GRADUATE MATHEMATICS 2010–2011

Department of Mathematics
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Preface

This bulletin is prepared annually for graduate students, and those considering graduate study, in the Department of Mathematics. It is intended as a supplement to the bulletin of the University of Utah Graduate School, which is available to all graduate students. The editors of this departmental bulletin welcome suggestions for its improvement from graduate students and members of the faculty.

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The University of Utah

CALENDAR OF EVENTS FOR 2010–2011

EVENT	Fall Semester 2010	Spring Semester 2011	Summer Term 2011
Class schedule available on the web	M, Mar 1	M, Sep 20, 2010	M, Feb 7
Classes begin	M, Aug 23	M, Jan 10, 2011	M, May 16
Last day to drop (delete) classes	W, Sep 1	W, Jan 19	W, May 25
Last day to add classes	T, Sep 7	M, Jan 24	T, May 31
Last day to elect CR/NC option	T, Sep 7	M, Jan 24	T, May 31
Tuition payment due	T, Sep 7	M, Jan 24	T, May 31
Last day to withdraw from term length classes	F, Oct 22	F, Mar 4	F, Jun 24
Last day to reverse CR/NC option	F, Dec 3	F, Apr 22	F, Jul 29
Classes end	F, Dec 10	W, Apr 27	W, Aug 3
Reading Day	n/a	H, Apr 28	n/a
Final exam period	M–F, Dec 13–17	F–H, Apr 29–May 5	H–F Aug 4–5
Grades available on the web	T, Dec 28	T, May 17	T, Aug 16
Annual University Commencement/Convocation Exercises		F, May 6	

Departmental Written Qualifying Exams (Prelims) . . . . M–W, Aug 16–18, 2010 and W–F, Jan 5–7, 2011
Math Dept. TA training for new graduate students . . . . Aug. 11–20, 2010

HOLIDAYS, RECESSES, BREAKS
(No classes, day or evening. University closed on holidays)

Fall Semester 2010

Labor Day Holiday . . . . M, Sep 6
Fall Break . . . . M–F, Oct 11–16
Thanksgiving Break . . . . H–F, Nov 25–26
Holiday Recess . . . . Sa, Dec 18–Su, Jan 9

Spring Semester 2011

Martin Luther King/Human Rights Day Holiday . . . . M, Jan 17
Presidents' Day Holiday . . . . M, Feb 21
Spring Break . . . . M–Sa Mar 21–26

Summer Term 2011

Memorial Day Holiday . . . . M, May 30
Independence Day Holiday . . . . M, Jul 4
Pioneer Day Holiday . . . . M, Jul 25

For additional information concerning registration dates and fee payment deadlines see the university schedule(s) at `http://www.sa.utah.edu/regist/registration/registration.htm`. Please note that these dates may change after printing.

GENERAL INFORMATION

A Brief History

The University of Utah is a state tax-supported, coeducational institution. Founded in 1850, it is the oldest state university west of the Missouri River. In recent years, the Graduate School has been awarding approximately 215 Ph.D. degrees per year. The University faculty consists of approximately 3100 members.

The Mathematics Department of the University of Utah now awards, on the average, about eight Ph.D. degrees per year. Over 200 people have earned this degree since 1954. Most of them have positions in state and private universities, but some hold nonacademic positions. Six have been awarded Sloan Research Fellowships, 12 have been visiting members of the Institute for Advanced Study in Princeton, and five have been awarded National Science Foundation Postdoctoral Fellowships.

Our present graduate faculty numbers 45. A number of the current faculty have received national awards including Sloan Fellowships and Presidential Young Investigator Awards. The University has also recognized members of our faculty with Distinguished Professor, University Distinguished Researcher and Teaching Awards. A list of current members of the faculty, with some of their papers, is included on pp. 40. The research interests of the faculty are the areas of specialization available for graduate studies. They include diverse areas in pure and applied mathematics such as algebraic geometry, arithmetic geometry, commutative algebra, differential geometry, geometric topology, group theory, materials and fluids, mathematical biology, mathematical cardiology, mathematical finance, mathematical physiology, numerical analysis, partial differential equations, probability and statistics, representation theory, and stochastic processes.

During the present year, 24 members of the Mathematics faculty are associated with government-sponsored research contracts.

The University's total enrollment is currently about 29,000. During 2009–2010, there were 31 men and 24 women who were Teaching Fellows and Assistants in mathematics. Our graduate students come from different areas of the United States as well as many foreign countries.

Research Facilities

The newly-remodeled and expanded Mathematics Branch Library collection in theoretical mathematics consists of 190 journal subscriptions, 15,000 bound journals and 12,000 books. In addition, the Marriott Library collection includes numerous books and journals of interest to mathematics researchers and scholars. There are extensive interactive computing facilities available in the Department.

Computing Facilities

The Department provides outstanding computing facilities for use by faculty, students and staff. In mid-2010, the fully-Internetworked workstation and microcomputer configuration included almost 300 systems in a range of models from these architectures:

- Apple Macintosh (43);
- DEC Alpha (1);
- Intel IA-64 Itanium (1);
- Sun AMD64 Opteron and EM64T Xeon (26);
- Intel IA-32 Pentium (1)
- PowerPC GNU/Linux (2)
- Silicon Graphics (3);
- Sun Ray stations (207);
- Sun SPARC (17);

These include at least one file server from each UNIX architecture. Operating systems and CPU types include Solaris (AMD64, SPARC, and IA-32), GNU/Linux (Alpha, AMD64, IA-32, IA-64, MIPS, PowerPC, and SPARC), FreeBSD (IA-32), IRIX (MIPS), MacOS (PowerPC), Minix (IA-32), NetBSD (IA-32), OpenBSD (IA-32), Plan 9 (IA-32), and Windows (IA-32 and AMD64).

A quad-processor 1.05GHz UltraSPARC-IV Sun Enterprise 2900 file server provides 10TB of storage, with a real-time mirror in another building to supply automatic switch-over should any storage or network component, or electrical power, fail. That file server is expected to be replaced in late summer 2010 by a newer and more powerful server.

Web and FTP services are each provided by separate operating-system domains on the central file server.

WeBWorK course services are handled by two quad-processor Sun W4100 (AMD64 Opteron) servers.

Sun Ray services on the Solaris SPARC architecture are handled by six quad-processor Sun Fire V440 systems and a 16-core Sun T5240, and on the GNU/Linux AMD64 architecture by an eight-processor Sun Fire X4600 system.

Batch computing services are provided by a dual-processor Itanium-2 server, three quad-processor AMD-64 servers, a quad-processor Apple Xeon Xserve system, and a Sun Blade 8000 server with four dual-CPU quad-core AMD64 blades (mathematical biology only) and two quad-CPU quad-core Xeon blades. Chassis space remains for an additional four blades to be added as funding permits.

All servers are located in a central machine room with its own cooling system and emergency power system, and network hubs share the same reliable power system.

Daily ZFS filesystem snapshots on the Sun Solaris file server provide immediate online access to user data from the last several weeks. All filesystems are backed up nightly to tapes covering the last few months, The tape server holds up to 500 LTO-4 tapes, each of 800GB raw capacity, and is shared with other departments in the College of Science.

The Mathematics and Physics Department student laboratories are open to members of either department, increasing the access possibilities; computer accounts are, however, managed within each department.

Each user has just one home directory, independent of login architecture, and all users have login access on all of the public workstations. Most standard programs are available on all architectures.

Eight large classrooms provide large-screen projection systems for workstation and videotape output, and there are two portable projection systems for conference-room display.

There are three Xerox 6360 color laser printers, an HP LaserJet 3700dn color laser printer, and about 50 distributed laser printers, including three high-volume duplex laser printers in the student laboratories. In addition, there are two Xerox WorkCentre Pro 65 black-and-white digital copier/printer/scanner systems (65 pages/minute), a Xerox DocuColor 3535 color digital copier/printer/scanner system (35 pages/minute), and a Canon imageRunner 8070 copier/printer (80 pages/minute).

All computer systems are reachable from anywhere on the global Internet, including home systems with DSL or cable modem Internet connections.

The facility is connected to the campus air-blown fiber-optic network backbone, which can provide several orders of magnitude in expanded network capacity, as the need arises. All network connections provide 10 Mbs, 100 Mbs, and 1 Gbs secure connections, and all offices have at least four ports.

All buildings, and adjacent outdoor areas, have wireless network access, managed externally by the University Office of Information Technology.

Research projects can apply for additional computer resources at the Center for High-Performance Computing on a 1024-node AMD64 Opteron cluster installed in mid-2004, and being upgraded in Fall 2008. Visit the CHPC Web site http://www.chpc.utah.edu/ for further details.

For more information about the Department and its activities and facilities, visit its Web site at http://www.math.utah.edu/. That site contains a link to an extensive frequently-asked questions (FAQ) repository that provides much more detail about our computing facilities.

Applications

To apply to the Mathematics Department degree program, you must apply to both the Mathematics Department **and** the University Admissions Office. Application materials and individualized application checklists may be found on our Web site http://www.math.utah.edu/grad/. The University application deadlines are **November 1st** for Spring admission, **March 15th** for Summer admission, and **April 1st** for Fall admission. The Mathematics Department deadline for teaching-assistantships applications is **January 15th**.

To expedite your applications for admission, please follow these procedures:

1. **University of Utah Admissions Office**
   (a) Apply online, or download the application at http://www.sa.utah.edu/admiss/appdownload/ and submit it by postal mail.
   (b) Supply these required documents:
      i. One copy of transcripts from each college or university you have attended, excluding the University of Utah. Transcripts you have had sent to the University of Utah in the past should be on file if you attended the University. Check with the Admissions Office if you have questions regarding this issue.
      ii. For international applicants:
         - Official transcripts in their original language accompanied by an English translated version.
         - Official TOEFL scores, unless applicant has attended a college or university in the U.S. in the last two years.
         - A copy of a national ID card or the photo-ID page of a current passport.
   (c) Pay the required application fees.
   (d) Track your admission status online regularly to verify that all required documents are received and processed.

   Note to international applicants: The I-20 form cannot be processed until *all* documents and fees are submitted to the Admissions Office *and* the student has been admitted by the program.

2. **Mathematics Department**
   (a) Download and complete the following forms from http://www.math.utah.edu/grad/:
      i. *Application for Admission*;
      ii. *Letter of Reference Form* (print three copies and follow instructions on the form);
      iii. *Financial Assistance Application* (optional).
   (b) Supply these required documents:

i. One copy of transcripts from each college or university you have attended. International applicants must provide official transcripts in their original language accompanied by an English translated version.

ii. Your GRE mathematics subject score. Starting with the 2010-year applications, we now require that you have your GRE scores sent to us.

iii. For international applicants, a copy of the official TOEFL and TSE scores, unless the student has attended a college or university in the U.S. in the last two years.

(c) There are no fees to apply to the Mathematics Department Graduate Program.

Admission to graduate status in either a Master's or Ph.D. program requires that students hold a Bachelor's degree, or its equivalent, with a **grade point average of at least 3.0** and that they show promise of success in graduate work.

Students are normally admitted at the beginning of the Fall Semester, and financial aid to new students is only offered at that time. It is desirable that applications for teaching fellowships and teaching assistantships, as well as other financial grants, be submitted as early as possible. Applications received before March 15th will automatically be considered for fellowships for the following Fall Semester.

Financial Aid

Most graduate students in mathematics are supported by teaching assistantships. Others may be supported by teaching fellowships, depending on the source of funding. (For convenience in this bulletin, *teaching fellowship* will usually be used to include both *teaching assistantship* and *teaching fellowship*, except where it is necessary to make a distinction between them.) Stipends and duties are discussed on p. **??**.

The Mathematics Department currently has two interdisciplinary programs funded by the National Science Foundation, and described as follows.

The Department of Mathematics successfully competed for a multi-year NSF VIGRE (Vertical Integration of Research and Education) grant and several fellowships may still be available through this program to U.S. Citizens and Permanent Residents. Awards are made once per year, and each award is for *one* semester for current students, and *two* semesters for incoming students. Those awarded receive stipend, a book allowance, and have no teaching duties for the semester. For more information on VIGRE, please visit http://www.math.utah.edu/vigre/.

Tuition

Tuition (nine hours) is approximately $2571 per semester for Utah residents and $8117 per semester for nonresidents. (Tuition rates may change without notice.) The Graduate Tuition Benefit Program administered by the Graduate School waives tuition fees for Teaching Fellows, Teaching Assistants, and Research Assistants. Graduate students who are supported by teaching assistantships are required to register for 12 credits per semester. The policy is described at http://www.gradschool.utah.edu/tbp/guidelines.php. All international students are required to pay $75.00 each semester to help cover additional administration costs that occur. **Supported students who withdraw after the drop deadline from a course covered by their tuition waiver will be financially responsible for the tuition of that course.**

Health Insurance

The University of Utah sponsors a health insurance plan at excellent rates for students, their spouses and their dependent children under age 26. For details, see http://www.studenthealth.utah.edu/services/SHI.htm.

The Graduate School and the Department provide each funded graduate student with a premium subsidy that covers the full cost of group health insurance offered through GM Southwest; see http://www.gradschool.utah.edu/tbp/insurance.php.

Housing

The University accepts applications for on-campus residence hall and University student apartment housing. Student residence halls provide a single room and a shared bathroom and kitchen. Visit the Web site http://www.housing.utah.edu/ for current information, or contact Office of Housing and Residential Living, 5 Heritage Center, University of Utah, Salt Lake City, Utah 84112-2036, (801) 587-2002.

Apartment housing for both married and single undergraduate and graduate students is available on campus. Visit the Web site http://www.apartments.utah.edu/ for current information, or contact University Student Apartments, 1945 Sunnyside Avenue, Salt Lake City, Utah 84108, (801) 581-8667.

Off-campus house and apartment listings can be found in the classified section of **The Salt Lake Tribune** (http://www.sltrib.com/), the **Deseret News** (http://www.desnews.com/) and the student newspaper, **The Daily Utah Chronicle** (http://www.dailyutahchronicle.com/).

PROGRAMS OF STUDY

The Mathematics Department offers programs leading to the degrees of Doctor of Philosophy, Master of Philosophy, Master of Arts, Master of Statistics, Master of Science in Mathematics, Master of Science in Computational Engineering and Science (see p. 13), and a Professional Master of Science and Technology Degree (PMST). Pending approval, it will soon be offering a Masters of Mathematics Teaching.

MASTER OF ARTS AND MASTER OF SCIENCE DEGREES

A. **Graduate School Requirements:**

The Master of Arts degree requires standard proficiency in one language — French, German or Russian. The Master of Science degree does not have a language requirement. Otherwise, the degree requirements for the M.S. and M.A. degrees are identical.

A number of forms must be filed, and certain time limitations are to be observed. Some remarks are in order relative to these requirements.

1. Comprehensive oral and/or written qualifying examination in mathematics are taken usually after a student has completed at least a year of graduate study. (See below.) The Master's Project requires a comprehensive final oral examination. This exam is called the project defense or thesis defense or the final oral examination.
2. Each Master's candidate will be assigned an academic advisor upon entering the program. This advisor has the primary responsibility of guiding and evaluating the candidate's progress through the Master's program. Questions concerning the interpretations of degree requirements should be directed to the candidate's advisor.
3. Thesis candidates must register for a minimum of six credit hours of thesis research Math 6970 and at least three credit hours per semester from the time of formal admission to the Graduate Program until all requirements for the degree including the final oral examination (thesis defense) are completed.

B. **Departmental Requirements:**

Requisites for the Master's degree in pure mathematics are:

Course Requirements

1. Math 5210 (real analysis)
2. Math 5310, 5320 (algebra)
3. One 6000-level sequence consisting of two one-semester courses
4. Four additional one-semester courses at the 5000- or 6000-level

Graduation Requirements

There are several options to satisfy the graduation requirements for the Master's Degree. The candidate may pass two qualifying exams and take 30 semester hours of coursework or do nine additional semester hours of Master's Project for a total of 39 hours of coursework.

There are four specific options.

1. *Qualifying Exam Option.* Pass two of the written qualifying exams **and** take at least 30 semester hours of approved courses. The exams are comprehensive and serve as the final exam.
   OR
2. *Curriculum Project Option.* Write a Curriculum Project and take at least 39 semester hours of approved courses. Students choosing this Non-Thesis Curriculum Project Option may take up to 10 semester hours of Math 6960 Special Projects. The Curriculum Project is in every other way a Thesis but does not need approval from the Thesis Office. The required final examination for this option is the public oral Final Defense of the Project.
   OR

3. *Courses Project Option.* Take additional courses at the 6000- or 7000-level for a total of at least 39 semester hours of approved courses. The required final examination for this option is the oral Final Comprehensive Examination.
   OR

4. *Thesis Project Option.* Write a Master's Thesis and take at least 39 semester hours of approved courses. Students choosing this Thesis Option may take up to 10 semester hours of Math 6970, Masters Thesis Preparation. The required final examination for this option is the public oral Final Defense of the Thesis. The University Graduate School's Thesis Office must approve the thesis and a copy of the thesis is archived by the University Library. By arrangement with the Graduate School, those students writing Master's theses may use credit hours in courses, numbered 6000 or above and in the general area of specialization of the thesis, to fulfill the 6–10 hours requirement of 6970 (Thesis Research).

The total number of semester hours required for the Master's degree in mathematics should fall in the range 30–39.

As specified by requirements of the Graduate School, a description of a nonthesis option and the basis for its selection shall be included with the student's proposed program. This statement and the proposed program of study must then have the approval of the departmental Director of Graduate Studies and be submitted to the Graduate Dean with the proposed program of study.

Requisites for the Master's degree in applied mathematics are:

Course Requirements

1. Either two 6000-level sequences, or 5210 and three 6000-level one-semester courses, two of which must form a year-long sequence.
2. Five additional one-semester courses at the 5000- or 6000-level.

Graduation Requirements

Same as those for the M.S. in pure mathematics.

A Comprehensive Examination

Such an examination is required by the Graduate School and is separate from the final oral examination in which a thesis is defended. The student's supervisory committee shall specify whether this examination will be an Oral Comprehensive Examination, or a Written Comprehensive Examination, or both. (Both may be required by the committee. A marginal pass of the written examination is one justification for requiring both exams.)

The Master's Oral Comprehensive Examination will be conducted by the student's committee and should be held at least one semester prior to the semester in which the student plans to complete the requirements for a Master's degree. The written examination will consist of passing the Written Ph.D. qualifying examinations in two areas.

Remarks and Suggestions

Courses which are offered regularly at the 5000-level include:

Pure Mathematics:

Math 5210	Real Analysis
Math 5310, 5320	Introduction to Modern Algebra
Math 5410, 5420	Ordinary Differential Equations, Dynamical Systems
Math 5520	Introduction to Algebraic/Geometric Topology

Applied Mathematics:

Math 5010	Introduction to Probability
Math 5040, 5050	Stochastic Processes and Simulation
Math 5080, 5090	Statistical Inference
Math 5110, 5120	Mathematical Biology
Math 5610, 5620	Introduction to Numerical Analysis
Math 5710, 5720	Introduction to Applied Mathematics
Math 5740	Mathematical Modeling
Math 5760, 5765	Introduction to Mathematical Finance

Students should also be aware of 5000-level offerings in other departments (e.g., courses in Biology, Chemistry, Computer Science, Economics, Physics, etc.) which can be applied to fulfill the course requirements for the Master's program in mathematics. Permission to include such courses must be obtained from the student's committee.

All graduate students who have not had an appropriate course in computer programming are strongly encouraged to consult faculty about appropriate classes in programming early in their program.

Students in the Master's program are expected to complete their Master's degree before entering the Ph.D. program. **(Only in exceptional cases will permission be given to enter the Ph.D. program without completing the Master's program.)** The normal schedule for Master's students who wish to continue for the Ph.D. is that they apply to the Ph.D. program during their final year as a Master's student and that they complete the Master's degree at the end of that year. Those who plan to take the written qualifying exam to complete their graduation requirements to the Masters Degree, may take those exams prior to the beginning of the Fall Semester of their second year. Their admission to the Ph.D. Program is contingent on their successful completion of these exams.

Financial support for the Master's program will be limited to two years.

Anyone wishing to pursue the study of mathematics toward a Ph.D. degree, but whose preparation does not qualify him/her to enter directly into the Ph.D. degree program, should enter the Master's program with the assurances that:

1. It will not hinder nor significantly delay his/her progress since it is the appropriate "next step" toward his/her goal.
2. Courses for the Master's degree will provide the introductory material and motivate the more abstract and theoretical approach to the same subjects in the Ph.D. program. However, successful completion of the Master's degree does not imply automatic acceptance into the Ph.D. program.

Acceptance and financial support for the Ph.D. program is awarded on the basis of a review of the application materials submitted, in a single competition among all applicants, irrespective of whether their previous degrees come from the University of Utah or other institutions. Applicants to the Ph.D. Program should make sure that their files are as strong as possible by supplying current letters of support.

All candidacy forms for the Master's degree should be submitted to the Graduate Coordinator who will forward them to the Graduate School.

C. **Sequence of Procedures for the Master's Degree**

There are time requirements and procedures that must be met in the course of completing a Master's degree. The following schedule is designed to help the candidate meet the necessary deadlines.

Schedule

1. **First semester of graduate work:**
   Discuss your proposed program with the Director of Graduate Studies at the beginning of the semester. By the end of the first year, choose a three-person supervisory committee. **It is the responsibility of the student to suggest a committee to the Graduate Advisor, who will be the committee chair.**

   Meet with your advisor towards the end of the Spring Semester to discuss your progress and any changes in your program. Discuss with him/her your chosen area of study and Master's degree project. It may be desirable for the Director of Graduate Studies to make some changes in the committee membership after you choose your area of study and your Master's degree project.

2. **One year before you plan to graduate:**
   Make the final plan for your course work and have it approved by your entire committee. Subsequent changes in the program are to be approved by your committee and reported to the Graduate School. Talk with members of your committee about plans for your comprehensive examination (to be taken early in the second semester of the second year) including topics that might be included on it; those of you choosing to take written qualifying exams should consult with your advisor on the best strategy for taking the exam. Remember, the oral comprehensive exam must be taken **before** scheduling a thesis or project defense.

3. **One semester prior to graduation:**
   File the *Request for Supervisory Committee* and *Application for Admission to Candidacy for a Master's Degree* forms with the Director of the Graduate School. These cannot be filed until at least one semester of graduate work is completed and must be filed at least one semester before you plan to graduate. (These forms may be filed on line. Copies can be picked up from the Graduate Coordinator.)

4. **Early in your final semester:**
   Candidates writing a thesis should schedule the (Defense of Thesis) Final Oral Examination with their supervisory committee. A *Handbook for Theses and Dissertations* is available in the Graduate School Office for details regarding the preparation and presentation of theses.

   If you are not otherwise enrolled for at least three credit hours during the semester in which you plan to defend your thesis, you must register for three credit hours of "Faculty Consultation" (mathematics 6980) before taking this final oral examination.

For graduation in a particular semester, one copy of the defended, committee approved manuscript must be submitted to the Thesis Office for "Format Approval" four weeks prior to the last day of the semester. For specific dates, consult *A Handbook for Theses and Dissertations*.

5. **Six weeks prior to graduation:**
   Have an acceptable draft of the thesis/project in the hands of your advisor. No time can be set for starting to write a thesis, since conditions vary. Consult with your advisor about the estimated time for writing a thesis.

   Several drafts of a manuscript are usually required before a final acceptable copy is reached. Consult with members of your committee regarding the stage at which they wish to see a copy.

6. **Five weeks prior to graduation:**
   Deliver a copy of the thesis to each member of your committee at least two weeks prior to the examination date.

   Review the Graduate School's *Graduate Program Calendar* for further information about procedures that should be followed in the final semester before graduation.

Time Limit

A period of four years is allowed to complete degree requirements for a Master's degree. Extensions beyond this four-year limit must be recommended by the supervisory committee and approved by the Dean of the Graduate School. The same time limit applies to M.S., M.A., M.Phil. degrees. Supported students are entitled to tuition waivers for a total of two years or four semesters for Master's degrees.

Transfer Credit

At most six hours of non-matriculated credit from the University of Utah or transfer credit from another university will be allowed in the graduate program toward a Master's degree.

D. **Recommended schedule of study toward a Master's degree with intent to enter the Ph.D. program.**

1. Master's degree students who subsequently **plan to apply for admission to the Ph.D. degree program** should proceed with the following *recommended* schedule:

YEAR	ACCOMPLISHMENTS
1	Study three 5000-level or 6000-level courses throughout the year. Where at least two 6000-level courses are studied, take at least two written qualifying examinations in the summer before the second academic year.
2	Study at least three courses at the 6000-level or 7000-level throughout the year. Apply for admission to the Ph.D. degree program no later than February 15. Complete the requirements for a Master's degree. Complete the written qualifying examinations by the summer before the next academic year.

Note: The following is quoted from *The University of Utah General Catalog 2011–2012*, *Graduate Information* chapter, p. 39:

> **Time Limit.** All work for the Master's degree must be completed within four consecutive calendar years. On recommendation from the student's supervisory committee, the Dean of the Graduate School can modify or waive this requirement in meritorious cases.

MASTER OF STATISTICS (MATHEMATICS) PROGRAM

A student is admitted to the program by the University Statistics Committee by making application through the Graduate School. If the University Statistics Committee admits the student, the Mathematics Department will admit him/her to its Master's program. No form needs to be signed by the Mathematics Department for this. Upon completion of the student's program, the University Statistics Committee will notify the Graduate School and the Mathematics Department. The degree, Master of Statistics (Mathematics), will be awarded by the Mathematics Department.

Prerequisites

1. Either a Bachelor's degree in Mathematics, or the equivalent, e.g., two years of Calculus and two senior level mathematics sequences.[1]
2. Math 3070, 3080, 3090, or equivalent.

Course requirements

1. Math 5010, 5080, 5090[2]
2. Stat 6070
3. One sequence of Math 6010, 6020
4. Electives approved by supervisory committee, 15 credits.
5. Math 6960 (Master's project) 3–6 hours.
6. Oral examination on the Curriculum Project (Math 6960), this is, a "Curriculum Project Defense."

MASTER OF MATHEMATICS WITH AN EMPHASIS IN TEACHING PROGRAM

The newest degree offered by the department is the Master of Science in Mathematics with emphasis in teaching. The teacher candidates will conduct research as part of their course work that will investigate content knowledge needed to successfully teach secondary school mathematics, and do so in a community of professional teachers who work together on improving mathematics instruction for all students. A student is admitted to the program by the Mathematics Education Committee by making application through the Graduate School. Upon admission by the Mathematics Education Committee, the student is also admitted to the Mathematics Department Master's program. The degree of Master of Mathematics with an Emphasis in Teaching is awarded by the Mathematics Department.

Prerequisites

1. either a Bachelor's Degree in Mathematics, Mathematics Teaching or related field with an equivalent of at least 6 of the courses required being level 4 mathematics endorsement courses
2. Praxis 2 (0061): Math Content Knowledge with a score of at least 143
3. Praxis (0063) Math Content Knowledge, and Mathematics: Proofs, Models and Problems, Part 1

The Mathematics Education Committee may advise candidates to take courses that would ensure their readiness for the required course work in the program.

Course requirements

The Graduate School at the University of Utah has a list of requirements for M.S.; see the University of Utah General Catalog http://www.ugs.utah.edu/catalog/. A total of 36–39 credits are required of a candidate: 30 are core courses, and will be taken by the cohort. The remaining 9 credits are to be electives with at least 6 from the discipline specific mathematics courses at 5000 level or above (any exceptions must be approved by the program coordinator). The candidates must take at least four 6000 level courses, of which at least two must be in the Mathematics department. Master's Project (93–96 credits): Students will conduct research and report on their findings in a thesis. The research topic must be approved by the student's committee before the research begins. The committee will be composed of at least two members of Mathematics Department and one member of College of Education.

Final Examination: Successful performance on a final oral examination which covers work presented for the masters degree and defense of the project. The following is a list of departmental requirements for candidates seeking a M.S. in Mathematics Teaching.

1. Math 5150 and 5160,
2. Math 6080 and 6090,
3. SPED 6141

[1] A "sequence" refers to a course that continues through an academic year.

[2] If Math 5010, 5080, 5090 was taken while the student was an undergraduate, then either one of Math 6010, 6020, 6040, 6070, or a mathematics sequence listed below is required.

4. 4 courses associated with licensure (if already held will be replaced by electives approved by the supervisory committee)
5. electives approved by the supervisory committee, 9-12 credits
6. Math 6960 (Master's project), EDU6960 Action Research
7. oral examination on project (Math 6960)

For more information, see http://www.math.utah.edu/mathed/master_mt.html or contact Gwen Allen, Program Assistant, The Center for Science and Mathematics Education, University of Utah, 155 S. 1400 E., Rm. 233, Salt Lake City, UT 84112-0090, (801)585-1985.

MASTER OF SCIENCE DEGREE PROGRAM FOR SECONDARY SCHOOL TEACHERS OF SCIENCE OR MATHEMATICS

The College of Science of the University of Utah, including the Departments of Biology, Chemistry, Mathematics and Physics, offers a Master's Degree program for certified secondary school teachers of science and mathematics. Started in 1972 by Acting Dean Allan Davis, the M.S. Degree Program for Secondary School Teachers of Science or Mathematics aims to help practicing teachers acquire a deeper and broader science background. The final goal is improvement in the quality of science and mathematics teaching in secondary schools.

The masters program works like this: Once accepted into the program, a graduate committee is appointed for the teacher. This committee works with the teacher to determine goals, and design an individualized program. The committee then supervises performance and progress.

Teachers begin their course work at a level compatible with their current knowledge and background. Teachers may take university courses in the subject they currently teach or may choose to focus on an allied area for certification or further enrichment. For example, a teacher who wants a better understanding of mathematical applications might choose to study highly quantitative courses in other sciences. On the other hand, a biology teacher may choose to concentrate on biology only or strengthen a chemistry background. In addition to regular university courses, those seeking the M.S. Degree for Secondary School Teachers may opt to attend seminar-type courses that teach science curriculum and teaching strategies.

Keeping the demands of a teacher's schedule in mind, enrollees are allowed to take fewer credit hours per semester. To complete the degree, each candidate must perform a Master's project, which may consist of lab work, field work, innovative pedagogy or a scholarly study of an advanced topic. A written report of this activity is required. This report will comprise six of the 30 to 33 semester hours required for degree completion.

Since the objective of the M.S. Degree program for secondary teachers of science or mathematics is to improve the quality of science teaching in schools, the desired applicant is a professional science or mathematics teacher who plans to stay in the field.

Admission requirements include:

1. Applicant must be accepted by an appropriate committee of the college.
2. Applicant must have a valid teaching certificate and be teaching science or mathematics in a secondary school.
3. Applicant does not need an academic or teaching major in the science subject he or she currently teaches to enter the program.
4. Applicant must have at least three years teaching experience and be recommended by a professional educator who can judge their performance.
5. Applicant must satisfy university requirements for graduate school admission.

MASTER OF PHILOSOPHY DEGREE

The Master of Philosophy (M.Phil.) degree requires the same qualifications for admission and scholarly achievement as the Doctor of Philosophy degree except that it does not require a doctoral dissertation. There is not a separate program for this degree. All supervisory committees, requirements in major and allied fields, and qualifying examinations apply to this degree. The Master of Philosophy degree, like the Doctor of Philosophy degree, is a terminal degree, and a student will not be considered a candidate for both degrees in the same department. The M.Phil. degree of a student desiring to pursue a doctorate in the department in which he/she was awarded the M.Phil. may be rescinded only by formal action of the Graduate Council on written request of the student.

MASTER OF SCIENCE IN COMPUTATIONAL ENGINEERING AND SCIENCE

The University of Utah Department of Mathematics and the School of Computing have established a joint degree program in *Computational Engineering and Science* (CES). In 2010–2011, the Mathematics members of the CES Coordinating Committee are Aaron Fogelson and Peter Alfeld. The CES program has a Web site at http://www.ces.utah.edu/.

1. To apply for admission into the CES program, a student must:
   - Have a background in the core areas of Computer Science, Mathematics, Physics, Electrical Engineering, Chemistry, Mechanical Engineering, etc.
   - Complete an application for the CES program, available at http://www.ces.utah.edu/future.html
   - Submit the application to the CES Steering Committee.
2. The requirements for the CES MS Degree are posted at http://www.ces.utah.edu/images/CES_Student_Handbook.pdf They include tracks with thesis, with courses, and with a project.

PROFESSIONAL MASTER OF SCIENCE AND TECHNOLOGY

The University of Utah Departments of Mathematics, Chemistry, Geology and Geophysics, and Physics have established a different kind of graduate degree *Professional Master of Science and Technology* (PMST). The PMST is a professional nonthesis, inter-departmental, and inter-disciplinary degree program that fuses multiple science fields with computational, management, and business skills. In this program, students will learn practical skills that will better prepare them for future employment and career changes. Telephone (801) 585-5630 for more program information.

The PMST program has a Web site at http://www.utah.edu/pmst/.

1. To gain admittance into the PMST program, a student must:
   - Be a graduating senior who is majoring in science.
   - Be a working professional looking to pursue a graduate degree.

PMST Curriculum

36 credit hours

1. Advanced Quantitative Skills (9 credits) data analysis, productive computing, reasoning.
2. Transferable Skills (9 credits) communication, project management, budgeting, decision making, negotiation skills, business and environmental law, basic interpretation of federal and state regulatory and policy issues.
3. Internship (3 credits) an internship or cooperative education experience in business, industry, commerce, or government agency.
4. Science Track (15 credits) Choose one of three science tracks: Computational Science, Science Instrumentation, or Environmental Science.

DOCTOR OF PHILOSOPHY DEGREE

A. **Graduate School Requirements:**

Please visit the Web site http://www.gradschool.utah.edu/catalog/degree.php for information on the Ph.D. degree requirements.

B. **Departmental Requirements**

1. **Supervisory Committee.** An academic advisor will be appointed for each prospective student prior to their first semester of graduate study. A Supervisory Committee will be appointed for each graduate student by the end of their first year of study. Any student may, at any time, request a change of advisor and/or committee. This request should be made in writing to the Director of Graduate Studies.

   The committee initially appointed for a student shall consist of three people, at least one of whom is in an area of the student's major interest. After the written qualifying examinations are passed, the committee shall be expanded to a committee of five as required by the Graduate School. Three members of the committee must be regular faculty members of the Mathematics Department and all must hold PhD's. One committee member must be from another department. Since a student's interests may change, the committee can be changed to reflect these interests.

   The function of the student's supervisory committee should be to advise, evaluate and certify. Specifically:

   a. The student should meet with his/her advisor at the beginning of each academic year to plan that year's work, and at least once a semester to discuss progress. The responsibility for setting these meetings rests with the student.
   b. The "Proposed Ph.D. Program", required by the Graduate School, should be worked out by the student and his/her committee at an early stage, and revised later if the committee considers it desirable.
   c. The committee sets its own ground rules on how it conducts the preliminary and final oral examinations. The student should arrange with the committee the scope of questions and how the exam will be conducted.
   d. Any special requests regarding financial aid or program of study should be submitted to the student's advisor.

   (For more information, see p. 22.)

2. **Course Requirements**

   a. Course requirements for the Ph.D. degree will consist of at least seven sequences numbered 6000 or above, or their equivalent, approved by the student's supervisory committee. The seven sequences required must include at least 14 credit hours of courses numbered 7800–7970 (topics courses, seminars, thesis research). The Department has made special arrangements with the Graduate School that credit in any of these courses qualifies as "Thesis Research". The graduate student's supervisory committee, if it deems it appropriate, may require additional courses and/or require specific courses.
   b. Exceptions to the above regulations must be approved on an individual basis by the Graduate Committee upon recommendation by the student's supervisory committee.

3. **Written Preliminary Examinations**

   The Written Ph.D. Preliminary Examinations are the same as the Master's Qualifying Examinations.

   a. **Time of the Written Qualifying Examinations.**
   The written qualifying examinations are given in January and August, usually in the week before the beginning of classes.
   b. **Written Qualifying Examination restrictions.**
   The written part of the Ph.D. preliminary examination in mathematics consists of three tests, in the following eight areas:

- Algebra
- Applied Mathematics
- Differential Equations
- Geometry and Topology
- Numerical Analysis
- Probability
- Real and Complex Analysis
- Statistics

Students should choose their tests in consultation with their advisor(s). One purpose of this consultation is to ensure sufficient breadth in the choice of tests. The student's choice of tests must be approved by the student's supervisory committee.

Registration forms for the examination are available from the Graduate Coordinator. A completed form must be returned to the Graduate Coordinator before the end of the semester preceding the exam.

In order to pass the written qualifying examinations, a student must pass three tests. Students entering with a strong background in undergraduate mathematics usually attempt all three qualifying exams in August before the beginning of their second year. Those who need to take 5000-level classes upon entrance will need an additional year to prepare for some exams, but all students should attempt at least one exam in August before the beginning of their second year, and must attempt three exams by August preceding their third year. Students have a two year time limit to pass all three tests. Students have a final opportunity to complete the exams in January of their third year (after completing five semesters of course work). Failure to pass at this time will result in termination in the graduate program at the end of the third academic year. A student is permitted to take a maximum of three exams each exam period, and may repeat a failed exam *only once*, and *only* at the discretion of the student's supervisory committee. Students who have taken graduate courses equivalent to our graduate qualifier preparation sequences may take the qualifying exams early. However, students are discouraged to take the exams until they can adequately prepare. The two year time clock begins when the student takes his/her first qualifying exam.

c. **Syllabus.**

The syllabi for the qualifying examination are included in this bulletin. These syllabi are the product of long discussions among the faculty in the various areas, and will not change from year to year, unless approved in advance by the Graduate Committee.

An important point for students to recognize is that the tests will be based on the material in the syllabus, NOT on the material in the preceding year's course on the subject. The student is responsible for preparing to be examined in all of the topics listed on the syllabus, whether or not all of the subjects were covered in a particular course on the subject. It usually takes a summer of study to acquire the global perspective on a subject needed to do well on the tests.

d. **Departmental committee on the examination.**

The Department Chairman appoints a member of the faculty (usually the Director of Graduate Studies) to make the arrangements for the written qualifying examinations of each academic year. This person will select two members of the faculty, in each of the various areas of the examination, to participate in the preparation and evaluation of the examinations.

e. **Description of the tests**.

The test in each area will be a written test of three hours duration. It is hoped that the inclusion of extra questions will reduce the factor of chance, and the student usually will have the option of omitting some of the questions without penalty. The level of the test should be comparable to that of the first-year graduate course in the field. The faculty members responsible for a given test should check to see that the topics covered on the test are compatible with the syllabus. Copies of past examinations are available on the Web at `http://math.utah.edu/grad/qualexams.html`. All examinations are proctored.

f. **Grading of the tests**.
After all the tests in a given area have been graded, the persons responsible for the test decide what is to be a passing score on the examination; in doing so, it is expected that they confer with and enlist the aid of their colleagues in the area of the examination. Student identities are not revealed to the graders.

g. **Announcement of results**.
Under normal circumstances the student is informed within one week after the end of the examinations of the passing score on each test and is allowed to examine their tests.

h. **Appeals**.
Exceptions may be granted to these rules in some cases. Grading of examinations may also be disputed. A student wishing to make an appeal will do so through their supervisory committee or the Director of Graduate Studies. These faculty members will assist the student in taking the necessary actions. A student may also enlist the aid of the Graduate Student Advisory Committee to help in the process. The names of the members of GSAC are listed in this bulletin.

4. **Oral Qualifying Examination**.
A student's supervisory committee shall conduct an oral qualifying examination no later than a date in the second semester (April 15 for Spring Semester and November 30 for Fall Semester) which follows the successful completion of the written examination. Students who fail the oral qualifying examination may be given a second examination **at the discretion of the student's supervisory committee**. Oral examinations may only be repeated once. Responsibility for scheduling the examination rests jointly with the student and his/her advisor. The oral examination is not a test of specific subject-matter retention; rather it is designed to measure the student's overall mathematics maturity and breadth, and his/her skill at chalkboard exposition and verbal exchange. In general the oral examination is concentrated on the area of specialization of the student and related areas. On the other hand, this oral examination is not a thesis defense, and should be conducted before much thesis research has been done.

The candidate initiates scheduling, with his/her supervisory committee approval. This examination should be scheduled as soon as possible after a thesis supervisor has been identified.

The supervisory committee sets its own ground rules for Ph.D. Oral Qualifying exams. The student should arrange with the committee the scope of questions and how the exam will be conducted. Most mathematics Oral Qualifying Exams have followed one of two plans:

A. The student answers questions based on his/her graduate courses.
B. The student makes a presentation of a background topic or on his/her preliminary research. The student proposes the plan for rest of the Ph.D. research. The student answers questions based on the presentation /proposal /graduate courses.

5. **Language Requirements**.
The Department of Mathematics does not have language requirements for a Ph.D. degree.

6. **Final Oral Examination**.
The final oral examination, sometimes called the "Thesis Defense," is distinct from the oral qualifying examination. This examination consists of a public thesis defense. The committee meets after the defense to vote on final approval.

7. **Teaching Requirements of Ph.D. Candidate**.
The Department requires each graduate student who is studying toward a Ph.D. degree to teach a minimum of two courses, or equivalent tutorials, or laboratory supervisions to be carried out over a minimum of one year and a maximum of six years, whenever appropriate.

8. **Time Limit**.
The time limit for completion of degree requirements for the Ph.D. degree, as set by the Department, is seven years. Normal progress is one or two years to pass the preliminary written qualifying examinations and advance to candidacy, and two or three additional years to complete the thesis work. The Graduate School limits the maximum number of years for which tuition waivers are granted to supported students. Currently, this is five years with a Bachelor's degree,

or four years with a Master's degree. Entrants with a Bachelor's degree who have taught in our graduate program for four semesters (two years) can request another year of waiver.

C. **Graduate School Schedule of Procedures for the Ph.D. Degree**

The Graduate School has prepared the *Graduate PhD Program Calendar* for students pursuing a graduate degree, available at the Web site http://www.gradschool.utah.edu/thesis/. See also http://www.gradschool.utah.edu/thesis/handbook.pdf for *A Handbook for Theses and Dissertations*.

D. **Recommended Schedule of Study Toward a Ph.D. Degree**

The following recommended schedules are considered desirable for Teaching Fellows in the Ph.D. degree program. The numbered years are presumed to begin when the Fall Semester begins and end at the start of the next Fall Semester. Some students, especially those who have previously studied in other Ph.D. programs, should shorten the schedules outlined here. Except where there are extenuating circumstances, Teaching Fellows who fall more than one year behind these schedules, or who fail to complete the written qualifying examination in two years should not expect their teaching fellowships to continue. The following procedure will be followed with a request for a review for extenuating circumstances:

1. The student submits a written request to his/her committee, with a description of the basis of the request.
2. The student's committee reviews the request and submits a written recommendation to the departmental Graduate Committee.
3. The departmental Graduate Committee makes a final decision regarding the request.

YEAR	ACCOMPLISHMENTS
1	Study three 6000-level courses throughout the year. Complete the written qualifying examinations at the end of the summer of the first year.
2	Study two or three advanced graduate courses. Attend some seminars. Try to select an area of specialty and a thesis adviser. Complete the oral qualifying examination. Complete the written qualifying examination if a second attempt is necessary.
3	Continue studying some advanced graduate courses. Participate in seminars. Begin work toward a thesis. Complete the oral qualifying examination if not done previously.
4	Devote primary attention to developing a thesis. Continue participating in advanced courses and seminars. Find some research topics to pursue beyond a thesis. Complete the requirements for a Ph.D. degree.

CONGRATULATIONS!!!

E. **Recommended Procedure for Ph.D. Degree Candidates also Wishing a Master's Degree**

Students who have entered directly to the Ph.D. Program who wish to pick up a Master's Degree along the way should basically follow the procedures outlined for Recommended schedule of study toward a Master's degree with intent to enter the Ph.D. program (see p. 10). See the Graduate Program Coordinator to arrange that required paperwork be sent to the Graduate School from the Department.

Course credits for the Master's degree and the Ph.D. degree may not be double counted. The coursework allotted for the Masters Degree is reported in the program of Study for the Master's Degree Form. The course requirements for the Ph.D. must be satisfied by the remaining courses. Although it is not usually a problem, since the student supported by a Teaching Assistantship has a limited number of tuition benefit semesters computed using the Universities formula, the student is responsible so make sure that tuition benefits cover the total semester hours needed for both the required Masters and Ph.D. coursework. This is another reason to register for the maximal hours allowed by tuition benefits each semester.

INSTRUCTIONS FOR THE PREPARATION AND SUBMISSION OF THESES, DISSERTATIONS AND ABSTRACTS

When accepted in partial fulfillment of the degree requirements, a Master's thesis or doctoral dissertation becomes the property of the University. However, publication rights are reserved to the author, subject to the provisions of research contracts, patent rights, or other agreements made by the author with the University.

A *Handbook for Theses and Dissertations* to be followed by the candidate in preparation of the thesis or dissertation is available from the Graduate School or the Thesis Editor. Information is included on bibliographic form and format approval, acceptable style manuals, registrar clearance, submission of the thesis or dissertation, submission of abstracts, and special fees.

It is important that the candidate procure a copy of these instructions before he/she begins the writing of the thesis. The student is invited to consult with the Graduate School Thesis Editor, in 302 Park Building, regarding the thesis or dissertations format. When the completed thesis is submitted a final release for graduation must be obtained from the Thesis Editor.

The use of restricted data for theses and dissertations:

1. Supervisory committees are responsible for approving topics for theses and dissertations and the approval must have the informed consent of the degree candidate to do the research requested.
2. No thesis subject may be approved that will prevent the completed thesis from being made available for public use by the time the degree is granted.
3. The supervisory committee shall schedule a public *Final Oral Examination* at which time the candidate must *defend the thesis* satisfactorily before the committee gives final approval of the thesis. This examination must be advertised on the campus one week before the examination data. Anyone may attend the presentation of the thesis.
4. The required number of copies of the completed thesis or dissertation must be submitted for public use to the University of Utah Library by the time the degree is granted.

Exceptions to items 2 and 4 above must be approved by the Graduate Council and can only be made by the Council in those cases where a delay is required to:

1. protect the rights of patent applicants,
2. prevent unjust economic exploitation, or
3. protect the privacy of research subjects.

Department Preparation of Theses, Dissertations and Abstracts

Student theses, dissertations and abstracts which are used toward degree requirements in the Department of Mathematics *will not* and *cannot* be *typed*, *duplicated* or *printed* by the departmental secretarial staff with University equipment. Please do not ask for special consideration. These restrictions apply to undergraduate and graduate student theses, dissertations and abstracts. The policy was set by the University, and is endorsed by the College of Science and the Department of Mathematics. Joint papers with faculty, individual nonthesis publications, mathematical reviews and similar publications will be produced by the Department, within the limitations of its resources.

The student should consult the thesis office program calendar frequently to ensure that they are submitting required forms in a timely manner to meet graduation deadlines. Forms are accepted throughout the semester, however, those students wishing a guaranteed graduation in a specific semester must meet the deadline dates listed on their program calendar. The program calendar can be picked up from the graduate program coordinator's office.

GUIDELINES FOR THE CONTINUATION OF FINANCIAL SUPPORT

The Department of Mathematics attempts to continue financial support to graduate Teaching Fellows and Teaching Assistants as warranted by the individual student's progress and budgetary limitations. We try to support the very best graduate students available. A grant of support is made to attract excellent students and to maintain them through their residency for a graduate degree in mathematics.

A general description of departmental policy for the continuation of financial support is given below. This policy covers some specific situations, but the Department reserves the option of flexible interpretation and redefinition of policy.

Continued financial support is recommended for graduate Teaching Fellows and Teaching Assistants who are making satisfactory progress in an approved program of study, and who are performing satisfactorily in their teaching duties. Responsible and capable teaching performance is essential for continuation. Incompetent teachers will not be supported, and cases of conspicuous irresponsibility or neglect will be cause for immediate termination. Besides teaching competence, progress toward a degree is the principal requirement for continued support. Each Teaching Assistant or Teaching Fellow must be enrolled and active as a student, in an approved program of study. Conspicuous neglect of courses, or withdrawal from them, can lead to termination of a teaching assistantship or fellowship. **There is a withdrawal penalty if a student's registration fall under the minimum requirement of nine credit hours or a student withdraws late from a course.**

All graduate TF's and TA's are eligible for the Graduate Tuition Benefit Program support, which is separately administered by the Graduate School. Students receiving the tuition benefit from the University of Utah Graduate School must be full-time matriculated graduate students in good standing. Full-time status for this purpose is registration of at least nine semester credit hours during the regular academic year. The tuition benefit is valid for a minimum of nine graduate credit hours and a maximum of twelve graduate credit hours for each semester. The department, however, requires that students receiving support should register for the maximum allowed by tuition benefits each semester, which for teaching assistants is 12 credits. There are limits on the number of years of eligibility (see http://www.gradschool.utah.edu/tbp/guidelines.php). **Students adding and/or dropping courses after the published university deadline(s) will be responsible for paying any fees and tuition incurred for that semester.** If current registration falls below nine semester credit hours at any time during the semester, the student becomes ineligible for the tuition benefit and will be billed for the full tuition for that semester. All international students must pay a fee of $75.00 each semester that the tuition waiver does not cover.

The following are guidelines and schedules for decisions regarding renewals of financial support:

Teaching Assistants in the Master's Degree Program

1. At the beginning of Spring Semester, evaluations are made by the Graduate Committee on the progress of all graduate students in their first year of study toward a their degree. Decisions to continue or award Teaching Assistantships are based on teaching performances and on performance and progress in graduate courses. Notification of renewals or nonrenewals are distributed by April 15.

2. Teaching Assistants are supported for at most two years in the Master's degree program. These appointments automatically terminate, without any special notice, at the end of the second academic year in the Master's degree program. Students who have been Teaching Assistants for less than a year, but cannot finish the degree program by the end of the second academic year, may request an extension of support and a decision whether to grant the request will be made by the Graduate Committee. Teaching Assistants who wish to apply for admission to the Ph.D. degree program should talk with their committees and attempt to follow the first schedule outlined on p. 17. Supported and unsupported Masters students who apply for teaching fellowships and admission to the Ph.D. degree will have their applications compared with those of all applicants, both at the University of Utah and at other institutions. It is the responsibility of the applicant to keep their file up to date with current letters of support.

Teaching Fellows in the Ph.D. Degree Program

1. For Teaching Fellows in their first year in the Ph.D. degree program, evaluations are made by the Graduate Committee at the beginning of Spring Semester. Decisions are based on teaching performances and progress in graduate courses. Notifications of renewals and nonrenewals are distributed by April 15.

2. For Teaching Fellows beyond their first year in the Ph.D. degree program, evaluations are made by the Graduate Committee at the beginning of Spring Semester. Decisions are based on teaching performances and on progress toward a Ph.D. degree, following the schedule outlined on p. 17. Notifications of renewals and nonrenewals are distributed by April 15. In some cases, renewals may be contingent upon the completion of specific requirements, e.g., a satisfactory performance on the qualifying examination, or the identification and pursuit of a suitable program of study and research.

3. Although the official time limit for a Ph.D degree is seven years (see p. 16, #8), the Department expects students to finish their Ph.D. requirements in at most five years, six years if there are special circumstances, and seven years only if there exists extraordinary reasons. Support for TAs/TFs then is expected to continue for at most five years (three years if the student enters with a Master's degree), any additional support will be given only if the Graduate Committee determines that there is sufficient grounds for continuation. The Graduate School guarantees tuition waivers to Ph.D. students entering with a Bachelor's degree for five years (three years for those entering with a Master's degree). The Graduate Tuition Benefit Program has been modified to extend the benefit for certain graduate students who serve as Teaching Assistants, and who entered with a Bachelor's degree. Such students who have served a minimum of four semesters as a full-time TA may earn an additional year (two semesters) of tuition waiver. Please check the Graduate School Web site for current information.

4. It is *extremely important* for graduate students to realize that their degree requirements can be met only if they take the written and oral qualifying examinations in a timely manner as outlined on p. 17.

Special Remarks to Graduate Students:

1. Take your teaching duties seriously and give attention to your obligations to the Department and to your students.

2. You will probably find that the pursuit of a Ph.D. degree in mathematics is a challenge and that it is not possible to plan and follow a rigid schedule toward the degree. While good performances on the qualifying examinations and in graduate classes are expected of students in the Ph.D. degree program, completion of these formal requirements does not in itself necessarily indicate satisfactory progress toward the Ph.D. Participation in seminars, informal discussions with other students and members of the faculty, and many hours of independent study and thought will be critical toward your development of a research thesis. In reality, your study of mathematics will need to be the dominant feature of your life and as such, **no outside employment will be allowed for TAs and TFs.**

3. In addition to classes, seminars, GSAC colloquia organized by students, and the Early Research Directions lectures, the Department of Mathematics sponsors Colloquium lectures that are intended primarily for graduate students and members of the faculty. Many of these lectures are presented by mathematicians who are invited from other institutions, and others are presented by members of the departmental faculty. Such a lecture usually includes some expository remarks in the first part, and then perhaps a more specialized discussion toward the end.

   The Department considers attendance at these lectures to be a important part of its program for graduate students and a sign that the student is serious about his profession. There are opportunities to hear about some important current mathematical developments, to receive suggestions of topics for further study, and to acquire familiarity with various areas of mathematics. There is much for you to gain from the lectures even where you have not had previous contact with the mathematical topics that are discussed.

SUPERVISORY COMMITTEES

Each graduate student will have an advisor and a supervisory committee. The supervisory committee can approve whatever program of study the student may choose, as long as it satisfies departmental and university guidelines. The committee will advise the student on selection of courses, and guide the student through the research and coursework. They will approve the students course of study, conduct oral examinations and sign off on the students work.

The student's advisor (mentor) will be initially appointed by the Director of Graduate Studies prior to the student's entrance into the program. The student will form a supervisory committee by the end of the student's first year in the program. Students may request a change of advisor or committee member at any time. This request should be made to the Director of Graduate Studies. Initially, the committee will consist of three members of the faculty; committees for Ph.D. degree candidates will later be expanded to a total of five. After an advisor has been appointed, **it is the student's responsibility to seek out his/her advisor to discuss a program of study**, and to meet periodically with that advisor at least once each semester.

1. The committee chairman (advisor) is usually chosen to be a faculty member whose research area is the potential research area indicated by the student. If the student expresses a personal choice, and if the faculty member suggested is not already overworked with advising, this person will usually be appointed.
2. The fourth and fifth members of the Ph.D. candidate's committee are appointed, in consultation with the student, after the written part of the qualifying examination is completed.
3. If the student's interests change, the committee makeup will be modified appropriately (by the Director of Graduate Studies after consulting the student and committee).
4. The function of the advisor and the supervisory committee should be:
   a. Advise the student regarding a program of study.
   b. Evaluate the student's progress in his/her program of study.
   c. Review any requests for changes or waivers in the usual requirements.
5. The student should make contact with his/her advisor every semester to discuss progress and possible changes in the program of study. Advisors are requested by the Director of Graduate Studies to make brief comments on each student's progress each semester.
6. A majority of the student's committee is sufficient to approve (or disapprove) his/her program, or petition for an exemption for some requirement. The student, or a dissenting member, can appeal any decision to the Director of Graduate Studies. Such an appeal will usually be reviewed by the departmental Graduate Committee. Appeals or recommendations which implicitly ask for a deviation from Graduate School policy must be reviewed by the Graduate School.

The supervisory committee sets its own ground rules about how it will conduct preliminary and final oral exams for both Masters and PhD students. It is the responsibility of the student to arrange with the committee the scope of questions and how the exam will be conducted.

THE GRADUATE STUDENT ADVISORY COMMITTEE (GSAC)

The Graduate Student Advisory Committee exists for the following reasons:

1. To advise new and continuing graduate students concerning curricula, requirements for degrees and other aspects of the graduate program.
2. To make recommendations to the Department concerning promotion, tenure and retention of faculty members.
3. To participate in the allocation of ASUU funds supplied to the College of Science Student Council.
4. To make whatever recommendations it feels appropriate concerning the graduate program to the Department of Mathematics.
5. To assist the Department in making its policies and requirements fully understood by the graduate students.

This committee shall consist of a number of members, elected in the spring of each year by the mathematics graduate students. For the school year 2010–2011 the members are:

- GSAC Co-Chairs
  - Victor Camacho, Chris Kocs, James Moore
- GSAC Retention Promotion and Tenure Committee
  - Stefano Urbinati (chair), Chris Kocs, Tony Lam, Dylan Zwick
- GSAC Colloquium Committee
  - Brendan Kelly (chair), Charles Cox, James Moore
- GNSAC Colloquium Refreshments Committee
  - Brittany Bannish (chair), Andrew Basinski, Sarah Cobb, Tony Lam, Jason Underdown
- Picnic Committee
  - Dylan Zwick (chair), Julian Chan, Becky Clover, Ron Reeder
- GSAC Recruitment Committee
  - Aaron Wood (chair), Chris Remien, Ben Trahan
- Social Outreach Committee
  - Brendan Kelly (chair), Tim Carstens, Bryan Wilson
- Web Page Maintenance
  - Chris Kocs

Student representatives from various disciplines

- *Mathematical Biology:* Brittany Bannish, Andrew Basinski, Victor Camacho, Charles Cox, James Moore, Chris Remien
- *Algebraic Geometry:* Tim Carstens, Stefano Urbinati, Dylan Zwick
- *Commutative Algebra:* Julian Chan
- *Topology/Geometric Group Theory:* Brendan Kelly
- *Representation Theory:* Ben Trahan
- *Number Theory:* Chris Kocs, Aaron Wood
- *Probability/Statistics:* Tony Lam, Ron Reeder

SYLLABI FOR QUALIFYING EXAMINATIONS

ALGEBRA

Topics and References

- GROUPS:

  Subgroups, quotient groups, cosets, permutation groups, symmetric and alternating groups, homomorphism and isomorphism theorems, p-groups, Sylow subgroups, Abelian groups, solvable groups. Lagrange's Theorem, Cayley's Theorem, Sylow's Theorems, structure of finitely generated Abelian groups.

  References: Cohn, Algebra I, 3.1–3.5, 9.1–9.2, 9.4–9.8. Herstein, Topics in Algebra, Ch. 2. Hungerford, Algebra, 1.1–1.6, 2.1–2.2, 2.4–2.7. Jacobson, Basic Algebra I, 1.1–1.10, 1.12–1.13. Lang, Algebra, 1.1–1.6, 1.9–1.10.

- RINGS:

  Ideals, quotient rings, polynomial rings, Euclidean rings, principal ideal domains, unique factorization domains, matrix rings, artinian rings, semisimple rings, finite-dimensional algebras. Jacobson radical, Jacobson Density Theorem, Artin–Wedderburn Theorem.

  References: Cohn I, 6.1–6.8, 10.1, 10.5. Cohn II, 4.6, 10.1–10.3. Herstein, Ch. 3. Hungerford, 3.1–3.3, 3.5–3.6, 9.1–9.5. Jacobson I, 2.1–2.3, 2.5–2.7, 2.9–2.11, 2.14–2.16. Jacobson II, 4.1–4.4. Lang, 2.1–2.2, 2.4, 5.2–5.4, 5.6, 17.1–17.5.

- MODULES:

  Submodules, quotient modules, semisimple modules, free modules, projective modules, injective modules, tensor products. Structure of finitely generated modules over principal ideal domains.

  References: Cohn I, 10.2–10.6. Cohn II, 3.1–3.2, 4.6, 4.10. Herstein, 4.5. Hungerford, 4.1–4.3, 4.5–4.6. Jacobson I, 3.1–3.8. Jacobson II, 3.5, 3.7, 3.10–3.11, 3.13. Lang, 3.1–3.5, 3.8, 15.2, 16.1.

- LINEAR ALGEBRA:

  Vector spaces, dimension, linear transformations, matrices, characteristic polynomials, trace, determinant, rank, rational canonical form, Jordan canonical form, diagonalization. Cayley–Hamilton Theorem, Gaussian elimination, (symmetric) bilinear forms, orthogonal, unitary, and hermitian forms, tensors and exterior algebras.

  References: Cohn I, 4.1–4.7, 7.1–7.3, 11.1–11.5. Herstein, 4.1–4.2, 6.1–6.9.

- FIELDS AND GALOIS THEORY:

  Extension fields, degrees, roots, geometric constructions, splitting fields, algebraic closure, algebraic and transcendental extensions, separable extensions, Galois groups, fundamental theorem of Galois theory, solvability by radicals, finite fields, primitive elements.

  References: Cohn II, Ch. 5, 6.1, 6.3–6.4. Herstein, Ch. 5, 7.1. Hungerford, 5.1–5.7, 5.9. Jacobson I, 4.1–4.13. Jacobson II, 8.1–8.3, 8.7–8.8, 8.14. Lang, 7.1- 7.6, 8.1–8.2, 10.6.

- HOMOLOGICAL ALGEBRA:

  Exact sequences, complexes, homology, categories, functors, Ext, Tor.

  References: Cohn II, 4.1–4.3, 4.8–4.9. Hungerford, 10.1. Jacobson II, 1.1–1.3, 6.1–6.3, 6.5–6.8. Lang, 4.1–4.2.

APPLIED MATHEMATICS

Topics

- FINITE-DIMENSIONAL LINEAR OPERATORS:

  Spectral theory, Fredholm alternative, generalized inversion, singular value decomposition, minimax principle.

- INTEGRAL AND DIFFERENTIAL OPERATORS:
  Contraction Mapping Theorem, compact operators, Hilbert–Schmidt theory, spectral theory, distributions, Green's functions, resolvent operators, method of images, discrete and integral transforms.
- CALCULUS OF VARIATIONS:
  Euler–Lagrange equations, Hamilton's principle, approximation techniques.
- COMPLEX VARIABLE METHODS:
  Analytic function theory, integral theorems, conformal mappings, contour integration, special functions, transform pairs, scattering theory.
- ASYMPTOTIC EXPANSIONS:
  Laplace's method, Watson's lemma, methods of steepest descent and stationary phase.

Text

- J. P. Keener, *Principles of Applied Mathematics: Transformation and Approximation*, Addison Wesley (1988) [ISBN 0-201-15674-1, 978-0-201-15674-4].

Other Texts

- G. Strang, *Linear Algebra and its Applications*, Harcourt, Brace, Jovanovich (1988) [ISBN 0-15-551005-3, 978-0-15-551005-0].
- B. Friedman, *Principles and Techniques of Applied Mathematics*, Wiley (1956).
- I. Stakgold, *Boundary Value Problems of Mathematical Physics, Vol. 1*, Macmillan (1967–1968).
- G. F. Carrier, M. Krook and C. E. Pearson, *Functions of a Complex Variable*, Hod Books (1983) [ISBN 0-07-010089-6, 978-0-07-010089-3].
- E. T. Copson, *Asymptotic Expansions*, Cambridge University Press (1967).
- R. Courant and D. Hilbert, *Methods of Mathematical Physics*, Interscience Publishers (1953–1962).

DIFFERENTIAL EQUATIONS

Topics

- Nonlinear analysis: 1. Contraction mapping principle 2. Implicit function theorem in Banach spaces-applications 3. Theory of Brouwer and Leray–Schauder degree 4. Fixed point theorems.
- Existence-uniqueness theorems for initial value problems: 1. Picard–Lindelöf theorem, Cauchy Peano theorem 2. Dependence upon initial conditions and parameters 3. Differential inequalities 4. Theory of linear systems, variation of constants formula. Floquet theory.
- Stability theory: 1. Stability of perturbed linear systems 2. Lyapunov stability.
- Sturm–Liouville problems and spectral theory.
- Hilbert space theory for linear PDE: 1. Distributions 2. Sobolev spaces, trace, Rellich embedding theorem 3. Lax–Milgram theorem 4. Applications of Lax–Milgram to the study of weak solutions of elliptic PDE's 5. Regularity theory 6. Spectral theorem for elliptic operators.
- Hille–Yosida–Phillips semigroup theory: 1. Strongly continuous semigroups of contractions and their generators 2. Hille–Yosida theorem 3. Phillips theorem 4. Parabolic PDE's 5. Unitary groups and the wave equation.

Text

- Lawrence C. Evans, *Partial Differential Equations*, American Mathematical Society, Providence, RI (1998) [ISBN 0-8218-0772-2].
- Robert C. McOwen, *Partial Differential Equations: methods and applications*, Second Edition ed., Prentice Hall, NJ (2003) [ISBN 0-13-009335-1].
- L. Perko, *Differential Equations and Dynamical Systems*, 3rd ed., Springer, New York (2000) [ISBN 0-387-95116-4]

- D. W. Jordan and P. Smith, *Nonlinear Ordinary Differential Equations– An Introduction for Scientists and Engineers*, 4th ed., Oxford (2007) [ISBN 978-0-199-21203-3]
- H. Amann, *Ordinary Differential Equations: An Introduction to Nonlinear Analysis*, de Gruyter, Berlin (1990) [ISBN 978-3110115154].
- K. Schmitt and R. Thompson, *Nonlinear Analysis and Differential Equations: An Introduction*, University of Utah Lecture Notes (2000). `http://www.scribd.com/doc/7847166/Nonlinear-Analysis-Differential-Equations-An-Introduction-Schmitt-Thompson`

GEOMETRY AND TOPOLOGY

Topics

- GENERAL TOPOLOGY:
  Metric spaces, paracompact spaces, Urysohn's Metrization Theorem, Tychnoff Theorem, Baire Category Theorem, Tietze's Extension Theorem, function spaces, [Dugundji, Singer–Thorpe]
- HOMOTOPY AND COVERING SPACES:
  Fundamental group, covering spaces, universal cover, Van Kampen's Theorem, computations of homotopy groups of $\mathbf{R}^n$, $\mathbf{S}^n$, $\mathbf{CP}^n$, etc., higher homotopy groups, homotopy sequence of a pair, Brouwer's Fixed Point Theorem, exact sequences of pairs and fibrations. [Hatcher]
- SIMPLICIAL AND CELL COMPLEXES:
  Simplicial complexes, barycentric subdivision, simplicial approximation, etc. [Hatcher]
- HOMOLOGY THEORIES:
  Including simplicial (and/or CW) and singular, axioms of a homology theory, universal coefficient theorem. Cohomology, cup products, Poincaré duality. [Hatcher]
- MANIFOLDS:
  Differential manifolds, construction of tangent bundle and cotangent bundle, exterior algebras, differential forms, DeRham cohomology, Froebenius theorem, Lie derivative, deRham theorem. Sard's theorem, transversality, degree theory, Gauss–Bonnet Theorem, vector fields, Poincaré-Hopf index theorem. [Guillemin and Pollack, Spivak]
- LIE GROUPS:
  Basic definitions, definition of Lie algebra. [Spivak]

Texts

- V. Guillemin and A. Pollack, *Differential Topology*, Prentice-Hall (1974) [ISBN 0-13-212605-2, 978-0-13-212605-2].
- M. D. Spivak, *A Comprehensive Introduction to Differential Geometry*, Publish or Perish (1979) [ISBN 0-914098-83-7 (hard), 0-914098-79-9 (soft), 978-0-914098-83-6 (hard), 978-0-914098-79-9 (soft)] (leisurely treatment of many topics in differential geometry).
- G. E. Bredon, *Topology and Geometry, Graduate Texts in Mathematics **139***, Springer (1993) [ISBN 0-387-97926-3 (New York), 3-540-97926-3 (Berlin), 978-0-387-97926-7 (New York), 978-3-540-97926-5 (Berlin)].
- A. Hatcher, *Algebraic Topology*, Cambridge University Press (2002) [ISBN 0-521-79160-X (hard), 0-521-79540-0 (soft), 978-0-521-79160-1 (hard), 978-0-521-79540-1 (soft)] `http://www.math.cornell.edu/~hatcher/`.

Supplementary References

- M. P. do Carmo, *Differential Geometry of Curves and Surfaces*, Prentice-Hall (1976) [ISBN 0-13-212589-7, 978-0-13-212589-5].
- M. J. Greenberg and J. R. Harper, *Algebraic Topology: An Introduction*, Addison-Wesley (1981) [ISBN 0-8053-3558-7 (hard), 0-8053-3557-9 (soft), 978-0-8053-3558-3 (hard), 978-0-8053-3557-6 (soft)].
- J. R. Munkres, *Topology—A First Course*, Prentice-Hall (1975) [ISBN 0-13-925495-1, 978-0-13-925495-6].

- W. S. Massey, *A Basic Course in Algebraic Topology*, Springer (1991) [ISBN 0-387-97430-X, 978-0-387-97430-9].
- J. J. Rotman, *Algebraic Topology, Graduate texts in mathematics **119***, Springer (1988) [ISBN 0-387-96678-1, 978-0-387-96678-6].
- I. M. Singer and J. A. Thorpe, *Lecture Notes on Elementary Topology and Geometry*, Springer (1967) [ISBN 0-387-90202-3, 978-0-387-90202-9].
- J. Dugundji, *Topology*, Wm. C. Brown (1989) [ISBN 0-697-06889-7, 978-0-697-06889-7].
- F. W. Warner, *Foundations of Differentiable Manifolds and Lie Groups*, Springer (1983) [ISBN 0-387-90894-3, 978-0-387-90894-6].
- S. Eilenberg and N. E. Steenrod, *Foundations of Algebraic Topology*, Princeton (1952) (Chapters 9 and 10, Cech homology).
- B. Gray, *Homotopy Theory: An Introduction to Algebraic Topology*, Academic Press (1975) [ISBN 0-12-296050-5, 978-0-12-296050-5].
- J. G. Hocking and G. S. Young, *Topology*, Addison-Wesley (1961).
- W. J. Pervin, *Foundations of General Topology*, Academic Press (1964).
- T. Benny Rushing, *Topological Embeddings*, Academic Press (1973) [ISBN 0-12-603550-4, 978-0-12-603550-6] (1.3, 1.4, 1.6D, 1.8, 2.2, 3.2).
- E. H. Spanier, *Algebraic Topology*, Corrected ed., Springer (1981) [ISBN 0-387-90646-0, 978-0-387-90646-1] (Chapter 2: Fibrations).
- N. E. Steenrod, *The Topology of Fibre Bundles*, Princeton (1951) (Ch. 1: Coordinate bundles and fibre bundles).
- S. Sternberg, *Lectures on Differential Geometry*, Prentice-Hall (1964).
- J. W. Vick, *Homology Theory: An Introduction to Algebraic Topology*, Academic Press (1973) [ISBN 0-12-721250-7, 978-0-12-721250-0], J. W. Vick, *Homology Theory: An Introduction to Algebraic Topology*, 2nd ed., Springer (1994) [ISBN 0-387-94126-6 (New York), 3-540-94126-6 (Berlin), 978-0-387-94126-4 (New York), 978-3-540-94126-2 (Berlin)].

NUMERICAL ANALYSIS

Topics

- NUMERICAL LINEAR ALGEBRA:

  Direct and iterative methods for solving linear algebraic equations. Error analysis. Methods for finding eigenvalues and eigenvectors. Singular value decomposition. Least squares.
- INTERPOLATION AND APPROXIMATION:
  Polynomial, rational, Fourier Series, spline based methods of interpolation and approximation. Quadrature.
- SOLUTION OF NONLINEAR EQUATIONS AND OPTIMIZATION:
  Contraction mapping principle, Newton's method, conjugate gradient method, steepest descent method, quasi-Newton methods, linear programming, constrained optimization.
- NUMERICAL SOLUTIONS OF DIFFERENTIAL EQUATIONS:

  Runge–Kutta methods, linear multistep methods for initial value problems of ODEs. Shooting, finite differences, finite elements for boundary value problems of ODEs. Finite difference and finite element methods for simple PDEs.

Texts

- E. W. Cheney, *Introduction to Approximation Theory*, 2nd ed., McGraw-Hill (1998) [ISBN 0-8218-1374-9, 978-0-8218-1374-4].
- P. J. Davis, *Interpolation and Approximation*, Dover (1975).

- J. E. Dennis, Jr. and R. B. Schnabel, *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, Prentice-Hall (1983) [ISBN 0-13-627216-9, 978-0-13-627216-8].
- R. Fletcher, *Practical Methods of Optimization*, Wiley (1987) [ISBN 0-471-27711-8 (vol. 1), 0-471-27828-9 (vol. 2), 978-0-471-27711-8 (vol. 1), 978-0-471-27828-3 (vol. 2)].
- G. H. Golub and C. F. van Loan, *Matrix Computations*, 2nd ed., Johns Hopkins University Press (1989) [ISBN 0-8018-3772-3 (hard), 0-8018-3739-1 (soft), 978-0-8018-3772-2 (hard), 978-0-8018-3739-5 (soft)].
- J. D. Lambert, *Computational Methods in Ordinary Differential Equations*, Wiley (1973) [ISBN 0-471-51194-3, 978-0-471-51194-6].
- A. R. Mitchell and D. F. Griffiths, *The Finite Difference Method in Partial Differential Equations*, Wiley (1980) [ISBN 0-471-27641-3, 978-0-471-27641-8].
- G. Strang and G. F. Fix, *An Analysis of the Finite Element Method*, Prentice-Hall (1973).
- R. Wait and A. R. Mitchell, *Finite Element Analysis and Applications*, Wiley (1985) [ISBN 0-471-90677-8 (hard), 0-471-90678-6 (soft), 978-0-471-90677-3 (hard), 978-0-471-90678-0 (soft)].

PROBABILITY

Topics

- Probability spaces, expectation, independence, Borel–Cantelli lemmas, Strong Law of Large Numbers.
- Weak convergence, characteristic functions, Central Limit Theorem.
- Conditional expectation, martingale convergence theorem, uniform integrability, optional stopping theorem.
- Countable Markov chains, recurrence, transience, stationarity, ergodicity.
- Brownian motion, sample path properties, Donsker's theorem.

Texts

- P. Billingsley, *Probability and Measure*, 3rd ed., Wiley (1995) [ISBN 0-471-00710-2, 978-0-471-00710-4].
- R. Durrett, *Probability: Theory and Examples*, 2nd ed., Duxbury Press (1996) [ISBN 0-534-24318-5, 978-0-534-24318-0].
- B. Fristedt and L. Gray, *A Modern Approach to Probability Theory*, Birkhäuser (1997) [ISBN 0-8176-3807-5 (Boston), 3-7643-3807-5 (Basel), 978-0-8176-3807-8 (Boston), 978-3-7643-3807-7 (Basel)].

REAL AND COMPLEX ANALYSIS

Topics

- MEASURE THEORY:
  Measurable spaces, measurable functions and positive measures. Integrable functions, integrals. Integration on locally compact spaces, Riesz representation theorem, regular Borel measures, Lusin's theorem. Integration on product spaces, Fubini's theorem. Complex measures, Radon–Nikodym theorem. Lp — spaces, duality.
- BASIC FUNCTIONAL ANALYSIS:
  Hilbert spaces, Banach spaces, Hahn–Banach theorem, Banach–Steinhaus theorem, open mapping theorem.
- COMPLEX ANALYSIS:
  Holomorphic functions, Cauchy–Riemann equations, Cauchy's theorem, Cauchy's integral formula, Power series, Taylor series of holomorphic functions, isolated singularities, Laurent series, Residue theorem, applications to calculation of definite integrals. Rouche's theorem, Conformal mappings, examples, maximum principle, Schwartz lemma, infinite products, Weierstrass factorization theorem. Analytic continuation, monodromy. Elliptic functions, modular functions and Picard's theorem.

Texts

- W. Rudin, *Real and Complex Analysis*, 3rd ed., McGraw-Hill (1987) [ISBN 0-07-054234-1, 978-0-07-054234-1].
- P. R. Halmos, *Measure Theory, Graduate texts in mathematics **18***, Springer (1975) [ISBN 0-387-90088-8, 978-0-387-90088-9].
- L. V. Ahlfors, *Complex Analysis*, 3rd ed., McGraw-Hill (1979) [ISBN 0-07-000657-1, 978-0-07-000657-7].
- W. Rudin, *Real and Complex Analysis*, 3rd ed., McGraw-Hill (1987) [ISBN 0-07-054234-1, 978-0-07-054234-1].
- J. Ogden and E. G. Milewski, *Schaum's Outline: The Complex Variables Problem Solver*, Research & Education Association (1987) [ISBN 0-87891-604-0, 978-0-87891-604-7].
- T. M. Apostol, *Modular Functions and Dirichlet series in Number Theory*, 2nd ed., Springer (1990) [ISBN 0-387-97127-0, 978-0-387-97127-8].

STATISTICS

- Maximum likelihood estimation and the method of moments. Unbiased estimation and the Cramer–Rao lower bound. Sufficiency, confidence intervals, hypothesis testing, likelihood ratio tests. Chi-squared tests of simple and composite hypotheses. Nonparametric methods. Linear and multivariate statistics.

Texts

- L. J. Bain and M. Engelhardt, *Introduction to Probability and Mathematical Statistics*, 2nd ed., PWS-KENT (1992) [ISBN 0-534-92930-3, 978-0-534-92930-5].
- P. J. Bickel and K. A. Doksum, *Mathematical Statistics: Basic Ideas and Selected Topics*, 2nd ed., Holden Day (Prentice-Hall) [ISBN 0-13-850363-X, 978-0-13-850363-5].

SYLLABI FOR UPPER DIVISION AND GRADUATE COURSES AND SEMINARS

The editors have attempted to make this listing as complete and accurate as current information will permit. However, additions, changes and deletions may occur because of enrollments, faculty leaves, availability of texts, and so on.

5010	**Introduction to Probability** (Fall, Spring, Summer Semester)
Instructors:	S. Ethier & F. Rassoul-Agha
Text:	R. Ash, *Basic Probability Theory*, Dover Publications (2008) [ISBN 0-486-46628-0, 978-0-486-46628-6]
Meets with:	**6805**
Prerequisites:	Math 2210
Topics:	This is a one-semester course in probability theory that requires calculus. Topics include combinational analysis, axioms of probability, conditional probability and independence, discrete and continuous random variables, expectation, joint distributions, and the central limit theorem.

5030	**Actuarial Mathematics** (Spring Semester)
Instructor:	L. Horváth
Text:	V. I. Rotar, *Actuarial Models: The Mathematics of Insurance*, Taylor and Francis ed., (2006) [ISBN 1-58488-586-6, 978-1-58488-586-3]
Prerequisites:	Math 5010 (grade B- or better required)
Topics:	This is a one-semester course in actuarial models that will help to prepare students for the third actuarial exam. Theory of interest, utility theory, individual and collective risk models, ruin models, survival distribution, life insurance models, annuity models, premiums. Additional topics as time permits.

5040, **5050**	**Stochastic Processes and Simulation I, II** (Fall, Spring Semester)
Instructor:	M. Joseph
Text:	R. Durrett, *Essentials of Stochastic Processes*, Springer (2001) [ISBN 0-387-98836-X, 978-0-387-98836-8]
Meets with:	**6810**, **6815**
Prerequisite:	Math 5010 or equivalent
Topics:	This is a two-semester course in stochastic processes and computer simulation that does not involve measure theory. The treatment is mostly rigorous, except that certain technical points may be taken for granted and computer simulation is used to enhance understanding. Topics may include Markov chains, Poisson processes, Markov processes, renewal processes, queueing theory, reliability theory, and Brownian motion. Applications will also be discussed.

5080, **5090**	**Statistical Inference I, II** (Fall, Spring Semester)
Instructors:	D. Conus and L. Horváth
Text:	L. J. Bain and M. Engelhardt, *Introduction to Probability and Mathematical Statistics*, 2nd ed., Duxbury (2000) [ISBN 0-534-38020-4, 978-0-534-38020-5]
Prerequisite:	Math 5010
Topics:	Functions of random variables, limiting distributions, statistics and sampling distributions, point estimation, sufficiency and completeness, special distribution theory, normal sampling theory, parametric estimation, confidence regions, hypotheses testing, introduction to linear models.

5110, 5120	**Mathematical Biology I, II** (Fall, Spring Semester)
Instructors:	F. Adler
Texts:	Recommended: L. Edelstein-Keshet, *Mathematical Models in Biology (SIAM Classics in Applied Mathematics **46**)*, SIAM (2005) [ISBN 0-89871-554-7, 978-0-89871-554-5] and G. de Vries, T. Hillen, M. Lewis, J. Muller, and B. Schonfisch, *A Course in Mathematical Biology: Quantitative Modeling with Mathematical and Computational Methods (SIAM Mathematical Modeling and Computation **12**)*, SIAM (2006) [ISBN 0-89871-612-8, 978-0-89871-612-2]
Meets with:	**6830**, **6835**
Prerequisites:	Math 2280, 3150, or equivalent
Topics:	Introduction to mathematical models which are used in ecology, cell biology, physiology and genetics. Techniques covered include ordinary, delay and partial differential equations, discrete time dynamical systems, and stochastic processes. Emphasis on modeling a biological system with appropriate tools, and using geometric and approximation techniques to derive answers to scientific questions.

5210	**Introduction to Real Analysis** (Spring Semester)
Instructor:	K. Bromberg
Text:	G. F. Simmons, *Introduction to Topology and Modern Analysis*, Krieger Publishing Company (2003) [ISBN 1-57524-238-9, 978-1-57524-238-5]
Prerequisites:	Math 3210, 3220, or consent of instructor
Topics:	Metric spaces, fixed-point theorems and applications, Lebesgue integral, normed linear spaces, approximation, Fourier series.

5310, 5320	**Introduction to Modern Algebra I, II** (Fall, Spring Semester)
Instructor:	C. Hacon
Text:	L. N. Herstein, *Abstract Algebra*, 3rd ed., Wiley (2001) [ISBN 0-471-36879-2, 978-0-471-36879-3]
Prerequisite:	Math 2250 *or* 2270, and Math 2900 *or* 3210
Topics:	(**5310**) This course begins with a review of the basic properties of sets and integers and continues with an introduction to group theory. It covers the definitions and basic properties of groups, abelian groups, symmetric groups, normal subgroups, and conjugacy. It also includes basic theorems on the structure of groups, Lagrange's theorem, and Sylow's theorem. (**5320**) This course is an introduction to the theory of rings and fields. During the first part of the course, we will study general concepts and the relationship between them: ring, field, ideal, maximal and prime ideal, homomorphism, quotient rings, integral domains and unique factorization domains. We then proceed with an in-depth study of various polynomials rings, applying as many of the concepts as possible. The course continues with the study of field extensions, and concludes with nonconstructibility proofs from geometry. Time permitting, we will study finite fields and/or the Galois correspondence.

5410, 5420	**Introduction to Differential Equations** (Fall, Spring Semester)
Instructor:	D. Tucker
Text:	R. Borrelli and C. Coleman, *Differential Equations*, 2nd ed., Wiley (2004) [ISBN 0-471-43332-2, 978-0-471-43332-3] (Fall, Spring)
Meets with:	**6840**, **6845**
Prerequisites:	Math 2220 and 3310; 2250; or instructor's consent.

Topics: (**5410**) Systems, existence, uniqueness, dependence on parameters, continuation, solution basis for constant coefficients, modeling, nonlinear systems, Laplace transforms

(**5420**) Series solutions of differential equations, linearization, rest points and stability, asymptotic stability, functions of mathematical physics, partial differential equations of classical physics (heat, wave, Laplace), Sturm–Liouville systems, orthogood expansion theory, applications.

5440 **Introduction to Partial Differential Equations** (Fall Semester)

Instructor: N. Korevaar

Text: H. F. Weinberger, *First Course in Partial Differential Equations*, Dover (1995) [ISBN 0-486-68640-X, 978-0-486-68640-0]

Meets with: **6850**

Prerequisites: Math 2250 or 2270, 2280

Topics: Classical wave, Laplace, and heat equations; Fourier analysis; Green's functions; Methods of characteristics.

5600 **Survey of Numerical Analysis** (Spring Semester)

Instructor: S. Isaacson

Text: J. D. Faires and R. L. Burden, *Numerical Methods*, 8th ed., Thomson/Brooks/Cole (2003) [ISBN 0-534-39200-8, 978-0-534-39200-0]

Meets with: **6855**

Prerequisites: Math 2210, Math 2250 or 2280

Topics: Numerical linear algebra, interpolation, integration, differentiation, approximation (including discrete and continuous least squares, Fourier analysis, and wavelets), initial and boundary value problems of ordinary and partial differential equations.

5610, 5620 **Introduction to Numerical Analysis I, II** (Fall, Spring Semester)

Instructor: J. Zhu

Text: R. Burden and J. D. Faires, *Numerical Analysis*, 8th ed., Brooks Cole (2004) [ISBN 0-534-39200-8, 978-0-534-39200-0]

Meets with: **6610**, **6620**

Prerequisites: Multivariable calculus, linear algebra, programming ability

Topics: (**5610**) Numerical linear algebra, polynomial interpolation, numerical differentiation and integration, nonlinear equations, approximation, optimization.

(**5620**) Continuation of Math 5610. Numerical solution of initial and boundary value problems of ordinary and partial differential equations.

5700 **Capstone Course in Mathematics** (Fall Semester)

Instructor: D. Allison

Text: To be announced

Prerequisites: Completion of two of the following: Math 3100, 3210, 3320, 4030, 4090

Topics: This capstone course examines topics in secondary school mathematics from an advanced perspective. Topics are drawn from Abstract Algebra, Geometry, Analysis, and Number Theory, each rooted in the core secondary school curriculum of number and operations, algebra, geometry, and functions. Students learn to formulate and generalize definitions and theorems that help to unite and explain mathematics. They draw connections between ideas taught separately in different courses. Through their work in this course, they improve their ability to promote their pupils' understanding of mathematics and to make better decisions regarding the direction of their lessons and curriculum.

5710, 5720 **Introduction to Applied Mathematics I, II** (Fall, Spring Semester)

Instructor: B. Alali

Text: G. Strang, *Introduction to Applied Mathematics*, Wellesley-Cambridge Press (1986) [ISBN 0-9614088-0-4, 978-0-9614088-0-0]

Prerequisites: Math 2250, 3150, 3160, 5710

Topics:	(5710) Symmetric linear systems, positive definite matrices, eigenvalue problems, equilibrium equations for discrete and continuous systems, boundary value problems in ODEs and PDEs, boundary integrals
	(5720) Fourier methods, initial value problems in ODEs and PDEs, conservation laws, network flows and combinatorics, optimization.

5740	**Mathematical Modeling** (Spring Semester)
Instructor:	E. Cherkaev
Text:	To be announced
Meets with:	**6870**
Prerequisites:	Math 5600 or CP SC 5220
Topics:	Development of mathematical models for physical, biological, engineering, and industrial phenomena and problems, using mainly ordinary and partial differential equations. Involvement of analytical and numerical tools suitable for analysis and visualization of the solutions of these problems.

5750-001	**Topics in Applied Mathematics: Composite Materials** (Fall Semester)
Instructor:	K. Golden
Text:	To be announced
Meets with:	**6880-001**
Prerequisites:	Math 5410/5420 or instructor's permission
Topics:	Homogenization and Optimal Design. Modern theory of homogenization, and applications to the optimal design of composite materials in conductivity and linear elasticity.

5750-002	**Topics in Applied Mathematics: Optimization** (Fall Semester)
Instructor:	A. Cherkaev
Text:	Jorge Nocedal and Stephen J. Wright, *Numerical Optimization*, 2nd ed., Springer (2006)
Meets with:	**6880-002**
Prerequisites:	Math 5410/5420 or instructor's permission
Topics:	This course discusses various direct methods, such as Gradient Method, Conjugate Gradients, Modified Newton Method, methods for constrained optimization, including Linear and Quadratic Programming, and others. We will also briefly review genetic algorithms that mimic evolution and stochastic algorithms that account for uncertainties of mathematical models. The course work includes several homework assignments that ask to implement the studied methods and a final project, that will be orally presented in the class.

5760, 5765	**Introduction to Mathematical Finance I, II** (Fall, Spring Semester)
Instructor:	J. Zhu
Text:	S. E. Shreve, *Stochastic Calculus for Finance I: The Binomial Asset Pricing Model*, Springer (2004) [ISBN 0-387-24968-0, 978-0-387-24968-1]
	S. E. Shreve, *Stochastic Calculus for Finance II: Continuous-Time Models*, Springer (2004) [ISBN 0-387-40101-6, 978-0-387-40101-0]
Prerequisites:	Math 2280 and 5010, 5040
Meets with:	**6890**, **6895**
Topics:	(5760) No arbitrage principle, risk-neutral measure and martingale, Black–Scholes–Merton model, stopping times and American options, random walks and exotic options.
	(5765) Brownian motion, Ito's calculus, Markov processes and Kolmogorov equations, Girsanov's theorem, derivation of Black–Scholes formula, some other exotic options, bonds and term-structure models, and an introduction to credit models.

5910-0XX	**Supervised Reading**
Instructor:	Staff

6010	**Linear Models** (Fall Semester)
Instructor:	S. Ethier
Text:	Bent Jørgensen, *Time Series: The Theory of Linear Models*, Chapman & Hall (1993) [ISBN 0-412-04261-4, 978-0-412-04261-4] G. Seber and A. LeeLinear Regression AnalysisPrentice Hall20020-13-044941-5, 978-0-13-044941-2
Prerequisites:	Math 5010, 5080, 5090, 2270
Topics:	Introduction to univariate linear modes. Simple linear regression. The general linear model. One-sample and one-factor analysis of variance. Multiple regression models. Analysis of residuals. Analysis of variance with two or three factors.

6020	**Multilinear Models** (Spring Semester)
Instructor:	S. Ethier
Texts:	R. A. Johnson and D. W. Wichern, *Applied Multivariate Statistical Analysis*, 6th ed., Prentice-Hall (2007) [ISBN 0-13-187715-1, 978-0-13-187715-3]
Prerequisites:	Math 6010
Topics:	Introduction to multivariate statistical analysis. The multivariate normal distribution. Mean and covariance estimation. Principal component analysis. Factor analysis. Regression and classification techniques.

6040	**Mathematical Probability** (Fall Semester)
Instructor:	D. Khoshnevisan
Text:	D. Khoshnevisan, *Probability*, AMS (2007) [ISBN 0-8218-4215-3, 978-0-8218-4215-7]
Prerequisites:	Math 6210
Topics:	This is a one-semester graduate course on the foundations of modern probability theory. Topics include the measure-theoretic construction of probability spaces and random variables, classical convergence theorems, martingale theory, and Brownian motion.

6070	**Mathematical Statistics** (Spring Semester)
Instructor:	L. Horváth
Text:	No Textbook
Prerequisites:	Math 2270, 5080, 5090
Topics:	Review of hypothesis testing and point estimation, introduction to simulations, bootstrap methods, and time series analysis.

6210	**Real Analysis** (Fall Semester)
Instructor:	K. Bromberg
Text:	W. Cheney, *Analysis for Applied Mathematics*, Springer (2001) [ISBN 0-387-95279-9, 978-0-387-95279-6]
Prerequisite:	Math 5210, 4200
Topics:	Measures and integrals, L_p-spaces, Hilbert spaces, Banach spaces, Fourier series.

6220	**Complex Analysis** (Spring Semester)
Instructor:	K. Bromberg
Text:	W. Cheney, *Analysis for Applied Mathematics*, Springer (2001) [ISBN 0-387-95279-9, 978-0-387-95279-6]
Prerequisite:	Math 4200, 6210
Topics:	Analytic functions, complex integration, conformal mapping, families of analytic functions, zeros of analytic functions, analytic continuation.

6240, 6250	**Lie Groups/Lie Algebras I, II**
Instructor:	D. Miličić
Text:	No Textbook
Prerequisite:	Math 6210, 6220, 6240 (basic understanding of differential geometry)

Topics: (6240) The course will cover the dictionary of Lie theory (Lie groups and Lie algebras, Lie subgroups, quotients) and fundamental theorems (like Cartan's theorem that any closed subgroup of a Lie group is a Lie subgroup). The course will also cover some basic properties of nilpotent, solvable and semisimple Lie algebras.

(6250) The course will first cover Lie algebra structure theory in more detail culminating with Levi's theorem stating that any Lie algebra is a semidirect product of a semisimple Lie algebra and a solvable ideal and Ado's theorem about the existence of faithful representations of Lie algebras in Lie algebras of matrices. The second portion will cover the structure theory of complex semisimple Lie algebras including the conjugacy theorems for Cartan and Borel subalgebras. This will lead to the classification of complex semisimple Lie algebras using their root systems. Finally, the compact forms of complex semisimple Lie algebras are constructed and this leads to the classification of compact Lie groups.

6310, 6320 **Modern Algebra I, II** (Fall, Spring Semesters)

Instructor: A. Singh

Texts: S. Lang, *Algebra*, Springer (2002) [ISBN 0-387-95385-X, 978-0-387-95385-4]

Prerequisite: Math 5320 or equivalent

Topics: Group actions, Sylow theorems, permutation groups, solvable and nilpotent groups, free groups and presentations. Rings and modules: Euclidean rings, PIDs, modules over a PID, canonical forms, applications to linear algebra. Fields: field extensions, finite fields, cyclotomic fields, Galois theory, transcendence degree.

6350 **Commutative Algebra** (Fall Semester)

Instructor: A. Singh

Text: H. Matsumura, *Commutative Ring Theory*, Cambridge University Press (1986) [ISBN 0-521-25916-9, 978-0-521-25916-3]

Prerequisites: Math 6320 or instructor's consent.

Topics: The course includes various topics in commutative algebra, including some homological algebra, Noetherian rings and modules, Hilbert's Nullstellensatz, primary decomposition, dimension theory, depth and regular sequences, Cohen–Macaulay, Gorenstein, and regular rings. A selection of more advanced topics will be chosen based on discussions with participating students.
The course may be repeated for credit when the topics vary.

6410, 6420 **Ordinary/Partial Differential Equations** (Fall, Spring Semester)

Instructor: A. Treibergs & D. Dobson

Text: J. Cronin, *Ordinary Differential Equations*, 3rd ed., CRC Press (2008) [ISBN 13-978-0-8247-2337-8] (6410) and L. Evans, *Partial Differential Equations*, 2nd ed., AMS (2010) [ISBN 13-978-0-8218-4974-3] (6420)

Prerequisite: Math 5210 or instructor's consent.

Topics: Existence/uniqueness/continuity theory for ODEs, linear ODEs, stability theory, invariant manifolds, Sturm–Liouville theory, spectral theory, PDEs of classical physics, Hilbert space methods, variational methods, distributions, regularity.

6510 **Differentiable Manifolds** (Fall Semester)

Instructor: K. Wortman

Texts: M. D. Spivak, *A Comprehensive Introduction to Differential Geometry, vol. 1*, 3rd ed., Publish or Perish (1999) [ISBN 0-914098-70-5, 0-914098-71-3978-0-914098-70-6, 978-0-914098-71-3] and
V. Guillemin and A. Pollack, *Differential Topology*, Prentice Hall (1974) [ISBN 0-13-212605-2, 978-0-13-212605-2]

Prerequisite: Math 4510 and 5520

Topics: Manifolds, tangent spaces, orientation, Whitney's embedding theorem, transversality, Sard's theorem, partitions of unity, tubular neighborhoods, fiber bundles, degree theory, vector fields, flows, Lie derivatives, Frobenius' integrability theorem, differential forms, DeRham cohomology.

6520	**Introduction to Algebraic Topology** (Spring Semester)
Instructor:	M Bestvina
Text:	A. Hatcher, *Algebraic Topology*, Cambridge University Press (2002) [ISBN 0-521-79160-X (hard), 0-521-79540-0 (soft), 978-0-521-79160-1 (hard), 978-0-521-79540-1 (soft)]
Prerequisite:	Math 5520, 6510
Topics:	Simplicial and cell complexes, homology and cohomology with coefficients, excision, Mayer–Vietoris sequence, cup and cap products, DeRham theorem, Euler characteristic, Poincaré-Hopf theorem, higher homotopy groups, long exact sequence of a fiber bundle, elementary homotopy theory.

6610, 6620	**Analysis of Numerical Methods I, II** (Fall, Spring Semester)
Instructor:	Y. Epshteyn
Text:	G. H. Golub and C. F. Van Loan, *Matrix Computations*, 3rd ed., Johns Hopkins University Press (1996) [ISBN 0-8018-5414-8, 978-0-8018-5414-9]
Prerequisite:	Math 5600 *or* 5620
Topics:	Mathematical and computational analysis of numerical methods in linear algebra, optimization, and ordinary and partial differential equations.

6630	**Numerical Solutions of Partial Differential Equations** (Spring Semester)
Instructor:	A. Fogelson
Text:	K. W. Morton and D. F. Mayers, *Numerical Solution of Partial Differential Equations*, Cambridge University Press (1994) [ISBN 0-521-41855-0, 978-0-521-41855-3]
Prerequisite:	Math 6610, 6620, Graduate course in PDE's.
Topics:	Review of analysis of numerical methods for linear one-dimensional partial differential equations (accuracy and stability). Solution of multi-dimensional linear and nonlinear PDE problems using multigrid approaches. Introduction to methods for nonlinear hyperbolic problems including level set methods.

6710	**Applied Linear Operator and Spectral Methods** (Fall Semester)
Instructors:	A. Cherkaev
Text:	J. P. Keener, *Principles of Applied Mathematics: Transformation and Approximation*, Addison-Wesley (1988) [ISBN 0-201-15674-1, 978-0-201-15674-4]
Prerequisites:	Math 5210, 5410 or equivalent
Topics:	The theory of linear operators applied to matrix, differential and integral equations, the Fredholm alternative, spectral theory, inverse and pseudo-inverse operators, Hilbert–Schmidt theory and eigenfunction expansions, wavelets, and Fast Fourier Transforms. Applications to a variety of problems of physics, biology, and engineering. This course along with Math 6720 forms the basis of the Applied Mathematics qualifying examination.

6720	**Applied Complex Variables, Asymptotic Methods** (Spring Semester)
Instructors:	A. Balk
Text:	J. P. Keener, *Principles of Applied Mathematics: Transformation and Approximation*, Addison-Wesley (1988) [ISBN 0-201-15674-1, 978-0-201-15674-4]
Prerequisites:	Math 3160, 6710
Topics:	The course will develop complex variable techniques used for studying ordinary and partial differential equations coming from physics. The emphasis is on applications rather than pure theory. Complex variable theory; contour integration, conformal methods and applications to solving differential equations, asymptotic methods for evaluating complicated integrals, transforms (including Fourier and Laplace transforms) and their application to solving partial differential equations, wavelets.

6730	**Perturbation Methods** (Fall Semester)
Instructors:	J. Keener
Text:	M. Holmes, *Introduction to Perturbation Methods*, Springer (1995) [ISBN 0-387-94203-3, 978-0-387-94203-2]
Prerequisites:	Math 6710 or equivalent.
Topics:	The course discusses the four basic problems of singular perturbation theory, namely singular boundary value problems, singular initial value problems, multiple time scale problems, and multiple space scale problems. The names of the techniques include matched asymptotic expansions, time scale analysis, multiple-time scale analysis, averaging and homogenization. Applications are made to a variety of problems in the physical and life sciences.

6740	**Bifurcation Theory** (Spring Semester)
Instructors:	J. Keener
Text:	Y. A. Kuznetsov, *Elements of Applied Bifurcation Theory*, Springer (1995) [ISBN 0-387-94418-4, 978-0-387-94418-0]
Prerequisites:	Math 6710, 6720
Topics:	In addition to the topics in the text, the course covers the Lyapunov–Schmidt method, global bifurcation theorems for Sturm–Liouville eigenvalue problems, the global Hopf bifurcation theorem, bifurcations in PDE's, the Ginzberg–Landau equation, the Turing instability and bifurcation (pattern formation), bifurcations such as the Taylor–Couette vortices, Benard instability, the thermoacoustic instability, and other related applications.

6750	**Continuum Mechanics: Fluid Dynamics** (Fall Semester)
Instructor:	A. Fogelson
Text:	P. K. Kundu, I. M. Cohen, and H. H. Hu, *Fluid Mechanics*, 3rd ed., Elsevier Academic Press (2004) [ISBN 0-12-178253-0, 978-0-12-178253-5]
Prerequisites:	Undergraduate ODE and PDE, or Consent of Instructor
Topics:	Derivation of equations of fluid dynamics, Euler and Navier–Stokes equations, Bernoulli's theorem, Kelvin's circulation theorem, potential flow, airplane lift, boundary layers, waves in fluids, fluid instabilities, turbulence, dynamics of the atmosphere and ocean.

6770, 6780	**Mathematical Biology I** (Fall and Spring Semester)
Instructor:	P. Kim
Text:	J. Keener and J. Sneyd, *Mathematical Physiology. II. Systems Physiology*, 2nd ed., Springer (2008) [ISBN 3-540-20882-8, 978-3-540-20882-2]
Prerequisite:	Consent of instructor.
Topics:	Systems physiology, including, blood physiology, circulation, electrocardiology, respiration, muscle physiology, endocrinology, the physiology of hearing and vision.

Note: All courses in the 6800 series meet with a 5000-series course, and are for Ph.D. students only. Extra work is required; this should be arranged with the instructor before the end of the second week of classes. See the 5000-series entries for descriptions.

6805	**Introduction to Probability** (Fall, Spring, and Summer Semester)
Meets with:	**5010**

6810, 6815	**Stochastic Processes and Simulation I, II** (Fall, Spring Semester)
Meets with:	**5040, 5050**

6830, 6835	**Mathematical Biology I, II** (Fall, Spring Semester)
Meets with:	**5110, 5120**

6840, 6845	**Introduction to Differential Equations** (Fall, Spring Semester)
Meets with:	**5410, 5420**

6850	**Introduction to Partial Differential Equations** (Fall Semester)
Meets with:	**5440**

6855	**Survey of Numerical Analysis** (Spring Semester)
Meets with:	**5600**

6870	**Mathematical Modeling** (Spring Semester)
Meets with:	**5740**

6880-001	**Topics in Applied Mathematics** (Fall, Spring Semester)
Meets with:	**5750-001**

6880-002	**Topics in Applied Mathematics** (Fall, Spring Semester)
Meets with:	**5750-002**

6890	**Introduction to Mathematical Finance I** (Fall Semester)
Meets with:	**5760**

6895	**Introduction to Mathematical Finance II** (Spring Semester)
Meets with:	**5765**

6910-0XX	**Supervised Reading**
Instructor:	Staff

6960-001	**GSAC Colloquium** (Fall, Spring Semesters)
Instructor:	A. Treibergs
Topics:	GSAC Colloquium. TA Training workshop.

6960-0XX	**Special Projects**
Instructor:	Staff

6970	**Thesis Research** (Masters)
Instructor:	Staff

7800-001 **Topics in Algebraic geometry: Moduli of Curves** (Fall Semester)

Instructor: Y.-P. Lee

Text: E. Arbarello and others, *Geometry of Algebraic Curves*, Springer-Verlag (1985) [ISBN 0-387-90997-4, 978-0-387-90997-4], and others

Prerequisite: Consent of Instructor

Topics:

- Hilbert schemes
- Nodal curves
- Deformation theory
- Moduli spaces of curves
- Projectivity of moduli spaces
- Line bundles on moduli spaces
- The Teichmüller point of view
- Smooth Galois covers of moduli spaces
- Cycles on the moduli space of stable curves
- Cellular decomposition of moduli spaces (via hyperbolic geometry)
- First consequence of the cellular decomposition
- Intersection theory of tautological classes
- The Hurwitz scheme

7800-001	**Topics in Algebraic Geometry** (Spring Semester)
Instructor:	E. Macri
Text:	To be announced
Prerequisite:	Consent of instructor.

7853	**Topics in Geometry / Topology** (Fall, Spring Semester)
Instructor:	M. Bestvina
Text:	No Textbook
Prerequisite:	Consent of Instructor
Topics:	Various topics in the area of geometric topology, to be offered on the basis of need or interest. May be repeated for credit when the topics vary.
7890-001	**Topics in Representation Theory** (Fall Semester)
Instructor:	P. Trapa
Text:	No Textbook
Prerequisite:	Consent of Instructor
Topics:	Various topics in representation theory, to be offered on the basis of need or interest. May be repeated for credit when the topics vary.
7970	**Thesis Research (Ph.D.)**
Instructor:	Staff

FACULTY 2010–2011

More complete bibliographies are available in the departmental office, and on faculty Web pages accessible via http://www.math.utah.edu/people/faculty.html.

DISTINGUISHED PROFESSORS

Bestvina, Mladen, University of Tennessee, 1984. Topology

Hacon, Christopher D., UCLA, 1998. Algebraic Geometry

Keener, James P., California Institute of Technology, 1972. Applied Mathematics

Milton, Graeme, Cornell University, 1985. Applied Mathematics

PROFESSORS

Adler, Frederick R., Cornell University, 1991. Mathematical Ecology

Alfeld, Peter W., University of Dundee, 1977. Approximation Theory

Balk, Alexander M., Moscow Institute of Physics and Technology, 1988. Nonlinear Phenomena

Bertram, Aaron, UCLA, 1989. Algebraic Geometry

Bressloff, Paul C., Kings College, University of London, 1988. Mathematical Biology

Brooks, Robert M., Louisiana State University, 1963. Topological Algebras

Cherkaev, Andrej V. Leningrad Polytechnical Inst., 1979. Optimal Design and Applications

Cherkaev, Elena, Leningrad University, 1988. Applied Mathematics

Dobson, David C. Rice University, 1990. Applied Mathematics

Ethier, Stewart N., University of Wisconsin, 1975. Applied Probability

Fogelson, Aaron L., New York University, 1982. Computational Fluids, Mathematical Physiology

Golden, Kenneth, New York University, 1984. Applied Mathematics

Gustafson, Grant G., Arizona State University, 1968. Ordinary Differential Equations

Hecht, Henryk, Columbia University, 1974. Lie Groups

Horváth, Lajos, Szeged University, 1982. Probability, Statistics

Khoshnevisan, Davar, University of California, Berkeley, 1989. Probability Theory and Mathematical Statistics

Korevaar, Nicholas J., Stanford University, 1981. Differential Geometry and Partial Differential Equations

Miličić, Dragan, University of Zagreb, 1973. Lie Groups

Savin, Gordan, Harvard, 1988. Automorphic Forms

Smale, Nathan, University of California, Berkeley, 1987. Differential Geometry

Taylor, Joseph L., Louisiana State University, 1964. Group Representations

Toledo, Domingo, Cornell University, 1972. Algebraic Geometry, Differential Geometry

Treibergs, Andrejs E., Stanford, 1980. Differential Geometry

Trombi, Peter C., University of Illinois, 1970. Lie Groups

Tucker, Don H., University of Texas, 1958. Differential Equations, Functional Analysis

ASSOCIATE PROFESSORS

Bromberg, Kenneth W., University of California at Berkeley, 1998. Topology

de Fernex, Tommaso, University of Illinois at Chicago, 2002. Algebraic Geometry.

Lee, Yuan-Pin, University of California, Berkeley, 1999. Algebraic Geometry, Symplectic Topology, Mathematical Physics.

Nizioł, Wiesława, Princeton University, 1991. Arithmetic Geometry

Rassoul-Agha, Firas, New York University, 2003. Probability Theory.

Singh, Anurag, Univ. of Michigan, 1998. Commutative Algebra

Trapa, Peter, Massachusetts Institute of Technology, 1998. Representation Theory

Zhu, Jingyi, New York University, 1989. Mathematical Finance

ASSISTANT PROFESSORS

Borisyuk, Alla, New York University, 2002. Mathematical Biology, Applied Mathematics.

Ciubotaru, Dan, Cornell University, 2003. Topological and Lie Groups.

Epshteyn, Ykaterina, University of Pittsburgh, 2007. Numerical Analysis.

Guevara Vasquez, Fernando, Rice University, 2006. Partial Differential Equations

Hohenegger, Chrystal, Georgia Institute of Technology 2006. Numerical Analysis, Fluid Mechanics.

Wortman, Kevin, University of Chicago, 2003. Geometric Group Theory.

ASSISTANT PROFESSOR (LECTURER)

Alali, Bacim, Louisiana State University, 2008. Partial Differential Equations

Cashen, Christopher, University of Illinois at Chicago, 2007. Group Theory

Conus, Daniel, Swiss Federal Institute of Technology, 2008. Probability

Dillies, Jimmy, University of Pennsylvania, 2006. Algebraic Geometry

Docampo Alvarez, Roi, University of Illinois at Chicago, 2009. Algebraic Geometry

Du, Jian, Stony Brook University, 2007. Numerical Analysis

Easton, Robert W., Stanford University, 2007. Algebraic Geometry

Joseph, Matthew, University of Wisconsin, 2009. Probability Theory.

Kim, Peter, Stanford University, 2007. Mathematical Biology

Lakuriqi, Enka, University of Pennsylvania, 2008. Algebraic Geometry

Lin, Joyce, University of North Carolina, 2009. Applied Mathematics.

Lodh, R.S., Rheinische Friedrich-Wilhelms University, 2007. Algebraic Geometry

Onofrei, Daniel T., Worcester Polytechnic Institute, 2007. Partial Differential Equations

Stirling, Spencer, University of Texas at Austin, 2008. Mathematical Physics

Tao, Jing, University of Illinois at Chicago, 2009. Geometric Group Theory.

Toth, Damon, University of Washington, 2006. Mathematical Biology

Yao, Lingxing, University of North Carolina, 2007. Numerical Analysis

Zajac, Mark, University of Notre Dame, 2002. Mathematical Biology

ASSOCIATE INSTRUCTORS

Alibegovic, Emina, University of Utah, 2003. Geometry and Topology

Allison, Dennis, University of Houston, 1970 (M.S.). Mathematics Education

Bestvina, Cyndi, University of Tennessee, Mathematics Education

Jovanovic-Hacon, Aleksandra, University of California, Los Angeles, 1997 (M.A.). Applied Mathematics

Keir, Marilyn, Stanford University, 1968 (M.A.). Mathematics Education

MacArthur, Kelly, University of Utah, 1995 (M.S.). Mathematics Education

van Opstall, Michael, University of Washington, 2004. Commutative Algebra. Mathematics Education

RESEARCH PROFESSORS

Beebe, Nelson H. F., University of Florida (Gainesville), 1972. Quantum Chemistry

Horn, Roger, Stanford University, 1967. Matrix Analysis

Palais, Robert, University of California, Berkeley, 1986. Applied Mathematics

RESEARCH ASSOCIATE PROFESSOR

Huang, Hsiang-Ping, University of California, Berkeley, 2000. Functional Analysis

RESEARCH ASSISTANT PROFESSOR

Adrian, Moshe, University of Maryland 2010. Number Theory, Algebraic Geometry.

Miller, Lance, University of Connecticut 2010. Number Theory.

Skorczewski, Tyler, University of California, Davis, 2010. Fluid Mechanics, Mathematical Biology.

Tucker, Kevin, University of Michigan 2010. Algebraic Geometry.

PROFESSORS EMERITI

Carlson, James A., Princeton University, 1971. Algebraic Geometry

Coles, William J., Duke University, 1954. Ordinary Differential Equations

Fife, Paul C., New York University, 1959. Applied Mathematics, Partial Differential Equations

Folias, Efthymios S., California Institute of Technology, 1963. Applied Mathematics

Gersten, Stephen M., Cambridge University, 1965. Group Theory

Glaser, L. C., University of Wisconsin, Madison, 1964. Geometric Topology

Gross, Fletcher I., California Institute of Technology, 1964. Group Theory

Mason, J. David, University of California, Riverside, 1968. Probability

Roberts, Anne D., McGill University, 1972. Analysis

Roberts, Paul C., McGill University, 1974. Commutative Algebra, Algebraic Geometry

Rossi, Hugo, Massachusetts Institute of Technology, 1960. Complex Analysis

Schmitt, Klaus, University of Nebraska, 1967. Nonlinear Analysis, Differential Equations